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PRESENTATION OF THE ALBERT MEDAL FOR 1956

His Royal Highness The Duke of Edinburgh, attended by Lieutenant-Commander Michael Parker, M.V.O., R.N.(retd.), visited the Society's House on 19th July, in order to present the Albert Medal for 1956 to Sir Henry Dale. The medal, as already announced in the *Journal*, was awarded to Sir Henry for 'eminent service to science, particularly physiology'. His Royal Highness was received on his arrival by Dr. R. W. Holland, Chairman of the Council, and by Sir Edward Crowe, Sir Ernest Goodale, Lord Radnor and Mr. E. Munro Runtz, Vice-Presidents of the Society, with Mr. K. W. Luckhurst, Secretary. The following members of the Council were then presented to His Royal Highness in the Library: Mrs. Mary Adams; Dr. W. Greenhouse Allt; Sir Alfred Bossom; Lord Cohen of Birkenhead; Sir Charles Dodds; Mr. P. A. Le Neve Foster; Mr. John Gloag; Sir William Halcrow; Lord Halsbury; Mr. A. C. Hartley; Lord Latham; Mr. F. A. Mercer; Mr. O. P. Milne; Sir William Ogg; Sir Selwyn Selwyn-Clarke; Sir John Simonsen; Sir Stephen Tallents; Mr. G. E. Tonge, and Miss Anna Zinkeisen, with Mr. R. V. C. Cleveland-Stevens, Deputy Secretary.

His Royal Highness the President, in presenting the medal, said:

The Council of the Royal Society of Arts have asked me to present you with this medal, which they have awarded to you to mark the very distinguished service to science which you have performed in, I think, a triple capacity: as an original thinker, as a teacher, and, as I think most remarkable of all, as an administrator. We would like you to know how much we admire all the work which you have done for a great many years and which you are still doing. On behalf of the Council and the Society it gives me great pleasure to hand to you this medal.

Sir Henry Dale replied as follows:

I am really profoundly grateful to you, Members of the Council, for the very high honour which you have done me in nominating me to receive the Albert Medal this year and to Your Royal Highness in graciously approving the honour and for making the special gesture, if I may say so, of finding time to come here personally to present it, thus adding greatly to the honour and to my memory of this occasion. We all know and sympathetically admire what we know to be the almost overlapping series of public duties which you discharge to the national admiration, and I ought not to delay you longer from that which I know you have already in view!

MODERN WELDING

Three Cantor Lectures by

H. G. TAYLOR, D.Sc.(Eng.), M.I.E.E., F.Inst.P.,

Director of the British Welding Research Association

LECTURE I

Monday, 16th April, 1956

In March, 1933, a series of Cantor lectures on Welding was delivered before this Society by Mr. Arthur Stephenson, who was at that time Vice-President of the Institution of Welding Engineers, an institution which later became the present Institute of Welding. These Cantor lectures by Mr. Stephenson make interesting reading to-day. Perhaps the easiest way to indicate the difference between the situation then and now is to mention those processes and applications which were not included in Mr. Stephenson's lectures. There is, for example, no reference at all to automatic welding, either submerged are welding or covered electrode. There is no reference to argon arc welding. The reference to resistance welding is very short: there is, of course, no self-adjusting arc welding which is our latest method of welding and, on applications of welding, there is no reference at all to welded bridges or to the use of welding in structures. There is very little reference to welding in ships and the references to pressure vessels are somewhat restricted. There is a delightful illustration showing a welded pressure vessel with, standing beside it, obviously one of the smallest men in the works, to emphasize the scale of the picture—a device which is quite unnecessary to-day when vessels up to twenty times the height of a man are commonly made by the same company. Mr. Stephenson naturally made great reference to gas welding, which was clearly a most important process at that time. In the course of the lectures which I shall give I shall make practically no reference to gas welding. This is not because it is no longer used, for that is indeed far from the case, but it cannot be described as a modern welding process in the sense that is has been developed in recent times, though it is, of course, still widely used. It is a curious feature that the introduction of something new does not always seem to displace the older method and this is particularly the case with gas welding. The process has been thought to be dying for many years, but in fact it is used more to-day than ever before. One can only assume that the increasing use of welding has led to an increasing field of application for gas welding. We have similar instances to this in everyday life. The introduction of the gramophone by no means displaced the piano, and the introduction of the wireless set had no adverse effect on the sale of the gramophone—in fact, rather the reverse. The provision of news bulletins on the wireless had no adverse effect on the sale of newspapers, and many other such cases could be quoted where, despite the forebodings and the direct predictions of disaster,

things have not turned out that way at all, and this is particularly the case with gas welding. It is widely used to-day, and there are applications for gas welding which cannot at all easily be met by any other process.

When Mr. Stephenson lectured to the Society, there were less than 3,000 welders in this country. By 1951, the number had increased tenfold, and is probably considerably higher again to-day. There are now 15 firms actively engaged in producing arc welding electrodes, and the striking development of this side of the industry is shown by the fact that whereas in 1938 the output of electrodes was only 11,720 tons, by 1944—under pressure of war-time requirements—the figure had increased to 45,000 tons. After the war, there was some reduction, but the output is again of this order to-day.

METAL ARC WELDING ELECTRODES

The metal arc welding process, as distinct from the carbon arc process, was first described in a patent granted to Slavianoff in 1890. In this process a metal electrode is used which not only provides means for making the arc, but also supplies the filler metal for the weld. In the early days of metal-arc welding bare wire electrodes were used. Various problems are, however, encountered when using bare electrodes. Whilst it is reasonably easy to start and maintain a D.C. arc with a bare electrode, difficulties are encountered when using A.C. The time during which the voltage is off usually allows the electrode tip and the parent metal to cool down sufficiently to make re-striking of the arc difficult or impossible when the voltage comes on again. Moreover, at the high temperatures which exist in the molten metal, the affinity of the material for foreign elements is increased, and there is a danger of impurities, mainly oxygen and nitrogen, entering either the molten particles travelling between the electrode and the parent metal, or the molten pool of metal. The oxygen will exist in the solidified steel mainly as ferrous oxide which causes hot shortness in the steel and loss of impact resistance at normal temperatures. Nitrogen produces embrittlement and is responsible for strain ageing.

COATED ELECTRODES

The difficulties contingent on the use of a bare electrode led to the introduction of the coated electrode, a most important and far-reaching development in metal arc welding. In 1907 Kjellberg took out a patent for an electrode to be dipped in or wrapped with a slow volatilizing substance which formed a vapour pocket round the arc. This patent may be considered the basis of shielded arc welding as we know it to-day.

The coating on the electrode serves four main purposes; it provides a gas which stabilizes the arc, this gas also shields the arc and prevents atmospheric contamination of the weld metal; it provides a flux which protects the weld metal and absorbs the impurities and oxides from the molten metal. Finally, the coating provides a means of introducing alloying elements in the weld metal. These various features were not all immediately appreciated by the early inventors. In 1911 Strohmenger drew attention to the advantages of asbestos

as a coating material when treated with sodium silicate. Such a coating was popular for very many years and was still in use thirty years later.

Such electrodes were wrapped with asbestos yarn and dipped. The dipping process was also used without wrapping and, in fact, for a limited range of electrodes is still used to-day. Essentially the process involves dipping the electrode a number of times into a slurry containing the necessary coating ingredients suspended in sodium or potassium silicate. It is sometimes necessary to keep the slurry continuously agitated to prevent settlement of high density minerals, but excessive agitation prevents the liquid adhering to the rod. Success turns on getting the right density of the solution and the right degree of agitation.

A highly significant step in electrode development was taken when, in 1917, Jones patented the extrusion process in which the coating in the form of a stiff paste is extruded through a die around the electrode which is forced through the centre of the die at considerable speed. Further details of the process are given later.

The similarity of the welding process to that of steel-making led to the use of coatings similar to steel-making fluxes—for example, iron oxide and silicon. One such type of coating is still commonly used and is known as the iron oxide type. The coating contains eighty per cent or more of iron oxide and may be used as a 'contact' or 'touch' rod, which minimizes operator fatigue, because the electrode may rest on the work and it is not necessary for the welder to hold a steady arc length. The voluminous slag resulting from the use of this electrode leads to a very smooth surface on the weld. The weld metal is nearly pure iron and naturally has less attractive mechanical properties than some other types of electrode.

The importance of arc shielding has already been referred to and American inventors were the first to introduce cellulosic compounds for this purpose. The theory behind the use of this material is that this compound is decomposed by the heat of the arc, principally into carbon monoxide and hydrogen, large volumes of which are generated from a comparatively small weight of cellulosic material. These gases surround the arc and form a reducing blanket excluding the atmosphere from the vicinity of the molten metal, and thus reinforcing the protective action of the molten slag formed from the metallic and mineral elements of the flux, against the oxygen and nitrogen of the air. Furthermore, the presence in the arc atmosphere of a large percentage of hydrogen raises the arc voltage of the electrode, and thus allows a higher power consumption per unit weight of core wire, making for a faster rate of welding.

The development of the large scale use of arc welding electrodes containing cellulosic material appears to have been associated originally with the A. O. Smith Corporation of Milwaukee, U.S.A., an engineering company which among other things, makes welded pressure vessels for the oil refining industry. The idea once having become familiar, a large variety of materials became available for discovery. The cellulose originally used for the purpose was probably powdered wood pulp, such as is used for paper manufacture, or possibly wood flour itself; though the latter is less satisfactory as it contains other constituents,

including a percentage of resin, in addition to cellulose. Wood pulp is practically pure cellulose, but has the property of 'felting' very readily, making the mechanical processes of dry and wet mixing with other powders rather difficult if a completely homogeneous mixture is to be obtained. It appears to have been substituted almost universally by a material known to the trade as Alpha flock. This is simply a wood pulp which has been chemically disintegrated into a powder form by an oxidation process. This oxidation process leaves the chemical constitution of the cellulose molecule practically unchanged but has the effect of breaking down the chemical bonds between the molecules which give the material its fibrous properties. The result is a powder which is much easier to incorporate uniformly into a plastic mixture.

A typical dry flux composition of this type of electrode would, according to Andrews, be as follows:

Alpha flock	40%
White asbestos powder (Chrysotile)	25%
Chemically prepared titanium oxide	15%
Ferro-manganese	15%
Other constituents	5%

The sodium silicate used as a binding agent forms a large proportion of the flux and the amount used has much to do with the success of this type of electrode—the characteristics of which are:

(*a*) high penetration;
(*b*) suitability for welding in various positions;
(*c*) good weld quality in heavy single runs.

A most important development in the electrode field was the appreciation of the utility of natural titanium oxide or rutile as a flux constituent. This material leads to an easy flowing electrode with good properties and good finish, which is very popular with welders. The slag is readily removed which is another attractive feature since it minimises welding time. Probably there are more electrodes of the rutile type used than any other. A possible coating composition is as follows:

Rutile	35% to 55%
Mineral silicates (mica, felspar, asbestos, etc.) ...	15% to 35%
Ferro manganese	5% to 20%
Basic carbonates (calcium, magnesium, or barium)	5% to 20%

British manufacturers now produce electrodes which are classified in six groups according to their flux covering, and this has now been accepted as a British Standard. The description of the electrode is as follows:

TYPES OF FLUX COVERING

Class No. 1 coverings having a high cellulose content

The covering contains at least 15 per cent of material having a high cellulose content with up to thirty per cent of titania (as rutile or titanium white).

This class of electrode is characterized by a deeply penetrating arc and rapid burn-off rate. Spatter loss is somewhat higher than with electrodes having the mineral type of covering. A voluminous gas shield is formed as a result of the decomposition of the cellulosic material in the arc region. The weld finish is somewhat coarser than usual, the ripples being rather more pronounced and less evenly spaced. The deposit has a thin cover of slag which is friable and thus easy to remove.

Because of its arc characteristics and the small volume of slag produced, the electrode is particularly easy to use in any welding position. With current values near to the maximum of the range, the electrode may be used in the flat position for 'deep penetration' welding.

The electrode is suitable for all types of mild steel welding and is of particular value for applications involving changes in position of welding, for example in pipe welding, storage tanks, bridges and shipbuilding.

Generally, this class of electrode is suitable for use with D.C. with the electrode connected to the positive pole. Some types are available which contain arc stabilizing materials, and may be suitable for use with A.C., although a high open circuit voltage is usually necessary.

Class No. 2 coverings having a high content of titania and producing a fairly viscous slag

The covering contains a high proportion of titania (as rutile, titanium white or ilmenite) and the high content of ionizers provides excellent welding properties.

Electrodes of this class are suitable for butt and fillet welds in all positions and are particularly easy to use for fillet welds in the horizontal-vertical position; sizes larger than 6 S.W.G. (3/16th in.) are not normally used for vertical and for overhead welding. Fillet welds tend to be convex in profile and have medium root penetration. The electrode has smooth arc characteristics and normally produces very little spatter. The slag is dense and completely covers the deposit, but is easily detached except from the first run in a deep v.

The electrode is particularly suitable for use with A.C., and on D.C. may be used with the electrode connected to either pole.

Class No. 3 coverings containing an appreciable amount of titania and producing a fluid slag

This type of covering contains an appreciable amount of titania (as rutile, titanium white or ilmenite), but the addition of basic materials yields a much more fluid slag than that produced by electrodes of Class 2.

Welding in the overhead and vertical (upwards) positions is far easier with this class of electrode than with any other type of mild steel electrode, but its use is not confined to these positions. The electrode has smooth arc characteristics, medium penetration, and normally produces very little spatter. The slag is generally easy to detach, even from the first run in a deep v.

The deposits produced by these electrodes will usually meet radiographic tests of normal standard more readily than those made with electrodes of Class No. 2.

The electrode is suitable for use with D.C. with the electrode connected to

either pole. On A.C. the electrode will usually work satisfactorily with open circuit voltages as low as 45.

Class No. 4 coverings producing an inflated slag having a high content of oxides or silicates of iron and manganese, or both

The coverings consist principally of oxides or carbonates of manganese and iron, together with silicates.

The electrode is generally produced with a thick covering and is used for welding in the flat position only. Certain varieties have a thinner covering, and these may be used for welding in all positions but have generally been superseded by other types of electrode. Both types of covering produce a fluid, voluminous slag which freezes with a characteristic internal honeycomb of holes the so-called 'inflated' slag, which is very easily detached. The weld finish is smooth, the ripples being much less pronounced than on deposits produced by the other classes of electrodes. In grooves and fillet welds the weld profile is concave.

The principal application for this class of electrode with a thick covering is for deep groove welding in thick plates, particularly where such welds are subject to strict radiographic tests. Certain varieties of this class of electrode are suitable for 'deep penetration' welding, particularly in fillets.

The electrode is suitable for use with D.C., usually with the electrode connected to the positive pole, and may be used on A.C. with a normal open circuit voltage.

Class No. 5 coverings having a high content of iron oxides or silicates producing a heavy solid slag, or both

This class of electrode has a thick covering consisting principally of iron oxides with or without oxides of manganese.

Electrodes of this class are used principally for single run fillet welds where appearance is of primary importance. The covering melts with a pronounced 'cupped' effect at the electrode tip, enabling the electrode to be used touching the work, this procedure being known as 'touch welding'. The degree of penetration is low. A heavy solid slag is produced which is sometimes 'self-detaching' and, in fillet welds, gives a smooth, concave profile.

These electrodes are sometimes referred to as 'dead soft' electrodes, because the weld metal has a low carbon content and a particularly low manganese content. This class of electrode has been used with some success for the welding of certain high tensile steels, and also steels having a higher content of sulphur than those used for structural welding, but on such steels the weld profile may be more irregular.

Weld metal deposited by these electrodes usually has low mechanical properties, the reduction of area and Izod impact values being generally less than the values normally specified.

The electrode is suitable for use on D.C. with the electrode connected to either pole. On A.C. the electrode will usually work satisfactorily with open circuit voltages as low as 45.

Class No. 6 coverings having a high content of calcium carbonate and fluoride

Coverings containing appreciable quantities of calcium carbonate and fluorspar

have been in use for a long time, but early types were not very popular with welders in this country. Improved types now available are quite satisfactory when used with the correct welding technique.

This class of electrode should preferably be used for welds in the flat position, but may be used for welds in other positions. The deposit is usually flat but with a marked surface ripple. The slag has a characteristic brown glossy appearance and rarely completely covers the deposit.

Certain makes of this class of electrode are sometimes called 'ferritic electrodes'; this is a misnomer, arising from their use for welding high tensile steels (armour plate) and to distinguish them from the austenitic electrodes used for that purpose. Their value for welding high tensile steel is generally attributed to the low hydrogen content of the weld metal.

To obtain the best results the electrodes should be thoroughly dried immediately before use, in order to remove any moisture they may have picked up during storage. The deposits are sound, and welds made with these electrodes are particularly suitable for fabrications to be exposed to very low temperatures.

The majority of these electrodes are suitable for A.C. or D.C., but when used with D.C. the electrode should be connected to the positive pole.

MANUFACTURE OF ELECTRODES

The method of manufacturing electrodes, and their composition, are secrets which are closely guarded by the electrode industry. Generally speaking, there are no fundamental differences in the method of construction between one electrode manufacturer and another, just as there are general types of electrode coatings which are fundamentally the same in composition. Nevertheless there are, both in manufacture and in composition, minor variations which make all the difference to the cost of production for example in one case, and to the quality of the electrode in the other. With respect to the composition of the coating, it will be well appreciated that competition in the field of electrode manufacture is very severe and any slight advantage which one manufacturer may gain over another may give him considerable profit. Naturally, therefore, he is not willing to disclose the precise composition of the coatings.

TABLE I. COVERINGS FOR PLAIN-CARBON OR LOW-ALLOY STEEL ELECTRODES

Material Formulæ—Parts by Weight

Gas shielded (E6010)		*Gas-slag shielded* (E6012)		*Slag shielded* (E6020)	
Cellulose ...	35	Cellulose ...	5	Iron Oxide ...	30
Asbestos ...	20	Rutile ...	55	Rutile ...	20
Titania	12	Asbestos ...	10	Clay	5
Sod. Sil. ...	80	Clay	10	Asbestos ...	15
		Iron Oxide ...	1	Sod. Sil. ...	70
		Sod. Sil. ...	40		

TABLE II. MINERAL COVERINGS FOR LOW-HYDROGEN ELECTRODES AND ELECTRODES FOR CHROMIUM CONTAINING HIGH-ALLOY STEEL

Material Formulæ—Parts by Weight

Low-hydrogen (E6015)		*'Lime' base type* (EXXX–15)		*'Titania' base* (EXXX–25) *type*	
Limestone ...	40	Limestone ...	35	Titania ...	30
Fluorspar ...	15	Fluorspar ...	30	Limestone ...	20
Cryolite ...	5	Asbestos ...	10	Fluorspar ...	15
Clay	5	Clay	8	Asbestos ...	7
Asbestos ...	5	Ferrosilicon ...	5	Clay	3
Ferrosilicon ...	5	Sod. Sil. ...	23	Ferrosilicon ...	5
Sod. Sil. ...	25			Sod. Sil. ...	28

Tables I and II show the approximate composition of six different types of American electrodes. It is not known how precisely these figures correspond with modern composition formulæ, but it may be assumed that they are generally of the right order and are sufficient to give an indication of the materials which are used in manufacture. The purposes which the various materials which are used in the coating serve, are set out in Table III overleaf, where on the left-hand side are indicated all the usual materials, and along the top the property for which the material is particularly used, such as arc stabilization, formation of slag, binding the coating together, and so on. It will be seen that many of the materials serve more than one purpose, and the importance of the function is indicated by marking it A for important, or B for a minor function.

Reference has already been made to the fact that there are two basic methods of coating electrodes; the first and oldest of these is the dipping process, and it is hardly necessary to explain this in any detail, except perhaps to say that the process is not one which is suitable for high-speed production. It presents considerable difficulties compared with extrusion of electrodes, the second and by far the most important method of construction.

Figure 1 illustrates roughly what happens in an electrode extrusion press. It will be seen that the wire electrode is fed in through a guide which it fits closely, and into the nozzle of the cylinder which contains the coating as a paste. The paste is submitted to a very high pressure, and extrudes through the die or nozzle with which the electrode wire itself is concentric. The paste is in such a dry condition that the paste-covered electrode can be handled on extrusion from the die. This is the essential condition for making high-speed production possible, for the rate of electrode feed is very high, many hundreds a minute. These electrodes, being projected more or less like bullets from a gun, have to be stopped and automatically arranged on a conveyor belt, and passed slowly through a drying oven.

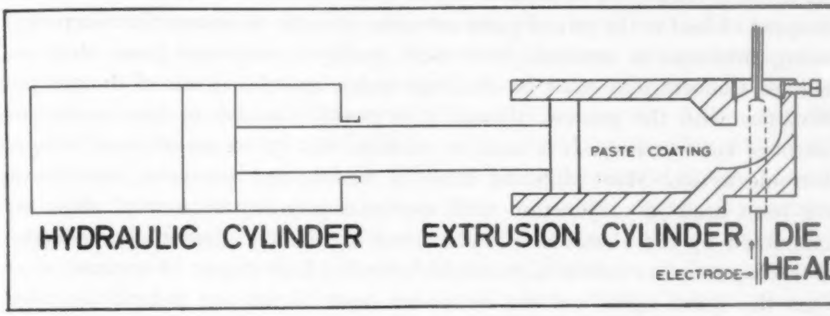
TABLE III. FUNCTION OF THE COVERING CONSTITUENTS IN ARC-WELDING ELECTRODES*

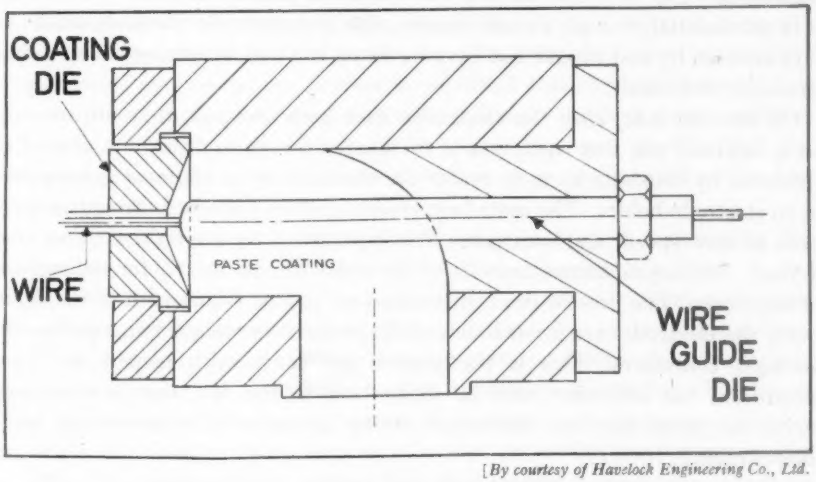
Covering constituent	*Arc stabilizer*	*Slag former*	*Reducing agent*	*Binder*	*Coating strengthener*	*Oxidizing agent*	*Gas shielding*	*Alloying weld metal*
Gum and/or resin	—	—	B	A	—	—	—	—
Cellulose	—	—	B	—	B	—	A	—
Felspar (alkali aluminium silicates) ..	B	A	—	—	—	—	—	—
Clay (aluminium silicates)	B	A	—	—	—	—	—	—
Talcs (magnesium silicates)	B	A	—	—	—	—	—	—
Titanates (rutile, titanium dioxide, etc.)	A	A	—	—	—	—	—	—
Iron oxides	B	A	—	—	—	A	—	—
Calcium carbonates	A	B	—	—	—	B	B	—
Asbestos	B	A	—	—	A	—	—	—
Ferro manganese	—	A	A	—	—	—	—	B
Potassium silicates or potassium salt ..	A	A	—	A	—	—	—	—
Sodium silicates	B	A	—	A	—	—	—	—

A = Principal function B = Minor function

* *American Welding Handbook*

This describes the essential and perhaps the most interesting part of the operation, but it should, of course, be explained that initially the requisite formula is made up from powders which are usually dry-mixed in the correct proportions, and then sodium silicate or other binder added when mixing proceeds. After this, the moist paste has to be converted into slugs, which can be handled, and put into the cylinder of the extrusion press. For this purpose, what is known as a slug-press is used, which compresses the paste and makes it into a suitable form for handling. The piston of the extrusion press is then completely withdrawn, and the slug of paste inserted in the cylinder. The piston is then returned, and a very high pressure exerted to cause extrusion. In a typical extruder the maximum thrust is 175 tons, the capacity of the cylinder is 1,220 cubic inches, and the maximum extrusion pressure 11,400 pounds per square inch. According to requirements, the flux cylinder bore can be increased or decreased. A larger bore gives more capacity at a lower extrusion pressure, and a smaller bore less capacity at a higher extrusion pressure. The choice of pressure is, of course, determined by the manufacturer's own requirements, and the type





[*By courtesy of Havelock Engineering Co., Ltd.*

FIGURE 1. *Electrode extrusion press*

of electrode which he is manufacturing. The operating times of the press are approximately as follows:

quick return—six seconds; rapid advance—twenty seconds; extrusion stroke at high speed takes three minutes.

A complete cycle at maximum extrusion speed can be completed in four to four and a half minutes, including the loading of slugs. This is just a typical machine, and others have different characteristics. The impressive feature perhaps to be noted is the fact that the extrusion pressure on the paste is no less than five tons per square inch.

This describes the commonest method of electrode extrusion but, in fact, other processes are known in which the paste is fed forward by a screw, much, for example, as in the case of the continuous extrusion press for lead sheathing for cables. The wire may be fed in continuously, and cut on the exit side of the machine, but much more generally it is cut prior to being fed into the machine and is fed in automatically. The speeds of feed are as high as 1,000 feet per minute; that is to say, over 600 18-inch electrodes per minute have to be coated. The speed of feed must be capable of fine control, since it is necessary to match the speed of feed to the rate of paste extrusion in order to ensure that the proper coating thickness is attained. Very high quality is expected from electrode coatings. Concentricity must be of a high order, and this is one of the greatest difficulties with the process, though it is possible to-day to have automatic control of concentricity. It is usual to measure this by means of some form of electronic device. Many different kinds of feeding and conveying mechanism have been used in conjunction with extrusion presses; frequently, these are constructed by the electrode manufacturers themselves. Essentially, however, the feeding must, as indicated, be controllable to a high degree of accuracy so as to get the speed right, and the electrodes must be fed one behind the other without any gap between; in fact, one electrode pushes the next one through. It is an essential, though a small feature, that the electrode wires should be cut very accurately, and should not have burrs on the end, otherwise unsatisfactory operation will result.

On the exit side, after the electrodes have been stopped, they are traversed on a belt and the first operation is to remove the paste from one end of the electrode by brushing so as to enable the electrode to be clamped subsequently in an electrode holder. The coated electrodes are then traversed through a drying oven at slow speed, and sometimes this is preceded by a certain amount of air drying. The drying temperature is of the order of 110–120°C. for the majority of electrodes. The process is a continuous one, and on coming out of the drying oven, the electrodes are immediately either counted or weighed and packed into air-tight containers. This is the general procedure with respect to drying electrodes, but reference may be made here to the fact that low-hydrogen electrodes must have an additional drying period at a considerably higher temperature.

SPECIAL ELECTRODES AND SPECIAL APPLICATIONS

The low-hydrogen electrode is one of the most important developments in

metal arc welding in the last ten years. During the war, it was perhaps first realized what an important *rôle* hydrogen played in weld metal, and it was discovered that its presence was closely related to the tendency of welds to crack. This was first pointed out by Hopkin, and there followed the development of what is known now as the low-hydrogen electrode. It was immediately apparent that water in one form or another was a prime source for introducing hydrogen into weld metal and, therefore, the low-hydrogen electrode was developed by means which would minimize the water content of its coating. There are two ways of doing this; one is to use a covering containing the minimum possible content of hydroscopic or combined water, and the other is to drive off as much water as possible in manufacturing the electrode. Both methods are used jointly, a combination of the proper choice of coating minerals with heating to a high temperature for drying. This naturally increases somewhat the cost of the electrode as compared with rutile electrodes, but the advantages are quite outstanding, and in certain circumstances the use of low-hydrogen electrodes is the only solution to satisfactory welding. Such electrodes have a high capacity for welding hardenable steels without cracking occurring in the heat-affected zone of the parent plate. The deposits are relatively free from micro fissures, also they have very good notch toughness at low temperatures and a much greater resistance to cracking in restrained welds than other types. Some of the early low-hydrogen electrodes had impact properties of fifty to seventy ft./lbs. at room temperature, whereas to-day 100 ft./lbs. is not unusual. The ductility of the weld metal has also improved by some ten per cent during the time of the use of such electrodes. It is interesting to record too that whilst rutile electrodes may have an Izod impact value at −70°C. of five to ten ft./lbs., a figure of twenty ft./lbs. is not exceptional for good quality low-hydrogen electrodes. A few years ago only two electrode manufacturers in this country were making a low hydrogen electrode; now all British manufacturers produce them, some in a range extending from mild steel to alloy steel with a tensile strength of seventy tons per square inch. There are to-day still developments in these electrodes, particularly aiming towards easy operation. It must be admitted that they are generally less easy to run than rutile electrodes, and every effort to improve their quality is worth while. Efforts are also being made still to improve the ductility, the tensile strength and the impact resistance, both at room temperature and at low temperatures.

One could wish that there were signs of progress towards minimizing the fume trouble which arises with these electrodes. Fluorospar is used in the coatings, and this gives rise to fluorine fumes which appear to be more unpleasant to the welders than ordinary welding fumes. A good deal of trouble has been caused from this source, and it is by no means certain whether there is any risk to health or whether the welder just suffers temporary discomfort. The broad solution appears to be to improve the ventilation where such electrodes are being used. When the work is being done in the open air or the semi-open air or a large shop, very little trouble arises. The chief trouble from fumes occurs in confined spaces, and naturally it happens that sometimes welding with

of electrode which he is manufacturing. The operating times of the press are approximately as follows:

quick return—six seconds; rapid advance—twenty seconds; extrusion stroke at high speed takes three minutes.

A complete cycle at maximum extrusion speed can be completed in four to four and a half minutes, including the loading of slugs. This is just a typical machine, and others have different characteristics. The impressive feature perhaps to be noted is the fact that the extrusion pressure on the paste is no less than five tons per square inch.

This describes the commonest method of electrode extrusion but, in fact, other processes are known in which the paste is fed forward by a screw, much, for example, as in the case of the continuous extrusion press for lead sheathing for cables. The wire may be fed in continuously, and cut on the exit side of the machine, but much more generally it is cut prior to being fed into the machine and is fed in automatically. The speeds of feed are as high as 1,000 feet per minute; that is to say, over 600 18-inch electrodes per minute have to be coated. The speed of feed must be capable of fine control, since it is necessary to match the speed of feed to the rate of paste extrusion in order to ensure that the proper coating thickness is attained. Very high quality is expected from electrode coatings. Concentricity must be of a high order, and this is one of the greatest difficulties with the process, though it is possible to-day to have automatic control of concentricity. It is usual to measure this by means of some form of electronic device. Many different kinds of feeding and conveying mechanism have been used in conjunction with extrusion presses; frequently, these are constructed by the electrode manufacturers themselves. Essentially, however, the feeding must, as indicated, be controllable to a high degree of accuracy so as to get the speed right, and the electrodes must be fed one behind the other without any gap between; in fact, one electrode pushes the next one through. It is an essential, though a small feature, that the electrode wires should be cut very accurately, and should not have burrs on the end, otherwise unsatisfactory operation will result.

On the exit side, after the electrodes have been stopped, they are traversed on a belt and the first operation is to remove the paste from one end of the electrode by brushing so as to enable the electrode to be clamped subsequently in an electrode holder. The coated electrodes are then traversed through a drying oven at slow speed, and sometimes this is preceded by a certain amount of air drying. The drying temperature is of the order of 110–120°C. for the majority of electrodes. The process is a continuous one, and on coming out of the drying oven, the electrodes are immediately either counted or weighed and packed into air-tight containers. This is the general procedure with respect to drying electrodes, but reference may be made here to the fact that low-hydrogen electrodes must have an additional drying period at a considerably higher temperature.

SPECIAL ELECTRODES AND SPECIAL APPLICATIONS

The low-hydrogen electrode is one of the most important developments in

metal arc welding in the last ten years. During the war, it was perhaps first realized what an important *rôle* hydrogen played in weld metal, and it was discovered that its presence was closely related to the tendency of welds to crack. This was first pointed out by Hopkin, and there followed the development of what is known now as the low-hydrogen electrode. It was immediately apparent that water in one form or another was a prime source for introducing hydrogen into weld metal and, therefore, the low-hydrogen electrode was developed by means which would minimize the water content of its coating. There are two ways of doing this; one is to use a covering containing the minimum possible content of hydroscopic or combined water, and the other is to drive off as much water as possible in manufacturing the electrode. Both methods are used jointly, a combination of the proper choice of coating minerals with heating to a high temperature for drying. This naturally increases somewhat the cost of the electrode as compared with rutile electrodes, but the advantages are quite outstanding, and in certain circumstances the use of low-hydrogen electrodes is the only solution to satisfactory welding. Such electrodes have a high capacity for welding hardenable steels without cracking occurring in the heat-affected zone of the parent plate. The deposits are relatively free from micro fissures, also they have very good notch toughness at low temperatures and a much greater resistance to cracking in restrained welds than other types. Some of the early low-hydrogen electrodes had impact properties of fifty to seventy ft./lbs. at room temperature, whereas to-day 100 ft./lbs. is not unusual. The ductility of the weld metal has also improved by some ten per cent during the time of the use of such electrodes. It is interesting to record too that whilst rutile electrodes may have an Izod impact value at −70°C. of five to ten ft./lbs., a figure of twenty ft./lbs. is not exceptional for good quality low-hydrogen electrodes. A few years ago only two electrode manufacturers in this country were making a low hydrogen electrode; now all British manufacturers produce them, some in a range extending from mild steel to alloy steel with a tensile strength of seventy tons per square inch. There are to-day still developments in these electrodes, particularly aiming towards easy operation. It must be admitted that they are generally less easy to run than rutile electrodes, and every effort to improve their quality is worth while. Efforts are also being made still to improve the ductility, the tensile strength and the impact resistance, both at room temperature and at low temperatures.

One could wish that there were signs of progress towards minimizing the fume trouble which arises with these electrodes. Fluorospar is used in the coatings, and this gives rise to fluorine fumes which appear to be more unpleasant to the welders than ordinary welding fumes. A good deal of trouble has been caused from this source, and it is by no means certain whether there is any risk to health or whether the welder just suffers temporary discomfort. The broad solution appears to be to improve the ventilation where such electrodes are being used. When the work is being done in the open air or the semi-open air or a large shop, very little trouble arises. The chief trouble from fumes occurs in confined spaces, and naturally it happens that sometimes welding with

low-hydrogen electrodes in such places is unavoidable. Then the only solution is to have a proper system for extracting the fumes, and perhaps to minimize the amount of time that the welder is exposed to such an unpleasant atmosphere.

It is well recognized to-day that the increasing temperatures and pressures which are used in power plant, call for better and better qualities of steel, but it is perhaps not generally realized that every improvement in the quality of steel—for example, in its creep properties, its fatigue resistance, or its notch toughness—demands that similar improvements should be made in the weld metal which is to be used in association with such materials. This places a great demand on the electrode industry, and research is continually in hand to match these improving characteristics of the base metal. In modern steam power stations, it is by no means unusual for pipes to operate at 500°C. (that is 930°F.) at which temperature the steel is nearly red hot and at this temperature weld metal must be satisfactory. To-day it is virtually impossible to imagine the construction of high power steam plants without welding, and there is no likelihood of any reversion to any other method of joining up steam pipes. In fact, the higher the temperature and pressure, the greater the demand for the use of welding. The industry has no option but to follow as fast as it can the developments in steel and operating conditions. Table IV gives some evidence of the characteristics which may be expected from modern electrodes. The silicate oxide type is shown together with two rutile electrodes and a number of low hydrogen electrodes including some specially useful for high-pressure high-temperature applications.

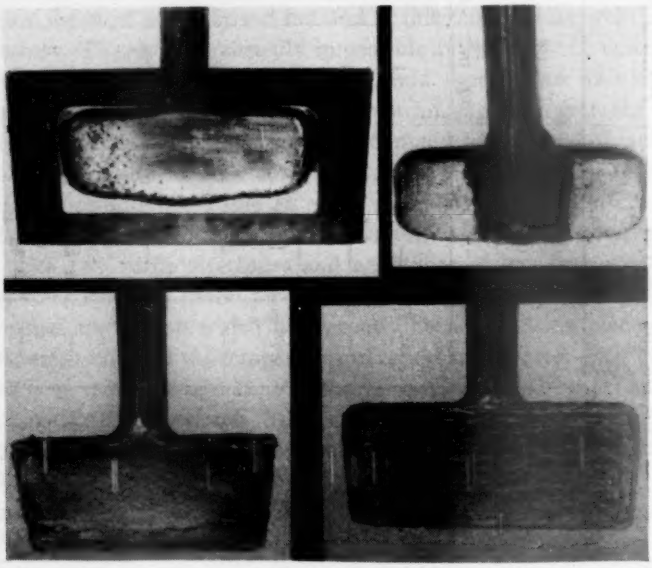
An unusual application which has recently been met, is an electrode having a high impact strength at the temperature of liquid air, namely, −190°C. A welded vessel has been made for operation at this temperature, and others are in course of construction. The electrode had at this temperature an impact resistance measured by the Izod test of ten foot pounds. Another problem facing the electrode manufacturers is the matching of electrodes to a particular steel. The requirements for gas turbines call for continuous operation at temperatures from 600 to 850°C. With prolonged operation at these temperatures, stainless steel containing a small amount of ferrite—as it must to avoid cracking when welding under conditions of restraint—is very liable to develop what is known as the sigma phase, a condition in which the impact strength and creep characteristics are poor. The steel is chosen very carefully to avoid this, and great skill is required to match an electrode so that the weld metal does not run into the same trouble. It is essential, for example, that the ferrite content of a mainly austenitic weld metal should not fall too low, otherwise cracking will occur during welding; neither should it be too high, otherwise the sigma phase will be encroached upon. There is some evidence that the amount of ferrite required to avoid cracking is linked with the amount of sulphur and phosphorus present; the lower these elements are, the less the amount of ferrite required and consequently the less the risk of sigma formation.

As a result of this situation, electrode manufacturers to-day are frequently making special electrodes to match particular steels. It is of interest to record that the magnetic permeability of the steel may be used as an approximate

TABLE IV. WELD METAL PROPERTIES

Electrode	Type	Weld Deposit Analysis C%	Mn%	Ni%	Cr%	Mo%	Physical Properties (all weld metal test pieces) Tensile strength tons/sq. in.	Yield point tons/sq. in.	Elongation %	Reduction of area %	Izod ft. lbs.
Silicate oxide type	Downhand electrode	0·06	0·35	—	—	—	31	28	28	45	50
Rutile type ..	do.	0·06	0·65	—	—	—	33	30	28	55	60
Do. ..	All position electrode	0·06	0·4	—	—	—	34	31	30	60	65
Low-hydrogen type	General purpose ..	0·08	0·9	—	—	—	35	31	30	70	90
Do. Do	High tensile All position	0·08	0·7	1·6	—	0·4	45	40	28	60	55
Do.	Creep resisting ..	0·08	0·9	—	1·25	0·5	47	42	23	61	50
Do.	do. ..	0·08	0·5	—	2·25	1·0	45	39	24	71	30
Do.	do. ..	0·08	0·5	—	4·5	0·5	50	—	20	50	—

measure of the ferrite content, and this has led to the development of a very simple device whereby the quality can be checked very readily. The device is known as a 'Ferrometer', or in its more popular pocket form, an 'Elcometer'. It is a pocket sized instrument, and its operation is based on the principle that the increase of magnetic flux directly between two soft iron probes of a U-shaped magnetic circuit, reduces the forces on a spring-loaded magnetic needle in a parallel magnetic branch. The tension of the spring can be adjusted so that the needle gives a scale reading corresponding to the ferrite content of a standard reference sample. In this way, using a set of standard samples for materials of different thicknesses, the ferrite content of production welds can be rapidly and easily checked. The range of the instrument is 0–30 per cent ferrite.



[By courtesy of Murex Welding Processes, Ltd.

FIGURE 2. *Ballast tamping heads before and after welding*

A general development which is taking place all the time is the improvement of mild steel electrodes so that they permit easier welding in specified positions. Another important application is the use of welding for hard surfacing. This is an old story, but the demands being made by the engineer on the electrode manufacturer are increasing all the time. It is in many cases essential that the surface should be as resistant as possible to wear, consistent with the absence of brittleness which would result in bits of the weld metal chipping off. A particular case of some interest is in the mechanical tamper which is used for tamping the ballast on railway lines. This is an old operation which has been done by hand in the past, but to-day mechanical tampers are used. The tamping heads, of which there are 16 in operation at once, have an amplitude of movement in the ballast of half an inch and operate at 28 blows per second. The wear on the heads

is naturally considerable, and they can only be kept in condition by frequent re-welding. An illustration of such a head is shown in Figure 2, together with the shape of it both before and after building up by welding.

The versatility of arc welding electrodes for hard surface application is quite remarkable. Surfaces can be provided ranging from the 250 V.P.N. required for clutch dogs on coal mining equipment or forging die blocks, to the 1800 V.P.N. of tungsten carbide grains deposited in a steel matrix on the tips of mechanical coal cutter picks, plough shares or horse-shoes.

It is perhaps of some interest to extend this list of applications. In the least hard range are the surfaces which are work-hardening due to the ready break-down of austenite to martensite. Deformation in service of the surface layer of a weld with this type of electrode immediately produces a relatively hard skin with a high resistance to abrasion, whilst the remainder of the deposit remains soft and ductile. Steel containing 12 to 14 per cent manganese, is frequently used for this purpose. This matches the composition of commercial manganese steel, and is particularly useful for rail crossings and dredger bucket lips. It is not unusual, with this type of coating, to provide a more ductile buffer layer between the base metal and the hard surface, thus minimizing cracking or chipping off. In this field are other electrodes producing work-hardening characteristics, but also providing a degree of corrosion and heat resistance.

Typical applications where work-hardening is required are: excavator teeth; stone crusher segments; swing hammers; coke oven pusher heads; valve seats.

In the non-austenitic group of hard surfacing electrodes, the degree of hardness depends on the rate of cooling after welding—the greater the rate of heat loss, the greater the hardness. Naturally the hardness can be controlled by heat treatment subsequent to welding.

With suitable choice of electrode and the use of temper hardening, it is possible to attain a hardness approaching 1000 V.P.N.—a hardness required by metal working or wood working cutting tools.

A hardness of about 350 V.P.N. is required by tractor track links and drive sprockets, steel mill rolls and mud pump valves; 650 V.P.N. is required by bulldozer blades, excavator teeth, scarifier teeth, scraper blades, pug mill knives (in brick-making machinery) and hot punches.

The use of tungsten carbide, referred to above, is commonly effected with a tubular steel electrode in which the carbide granules, with a suitable fluxing material, are held within the tube. Such a method is applicable for gas welding or for carbon or metal arc welding. Alternatively tungsten carbide inserts may be secured by welding. Many grades of tungsten carbide are used according to the application which may include rock drill bits, post hole augers, plough shares, shredding knives in the paper industry and many other applications particularly in connection with oil drilling, mining and agriculture.

It may safely be said that the introduction of these various types of electrode has revolutionized the problem of maintenance in many industries. The ease and economy with which worn parts may be repaired and made good by welding, has made a vast difference in the use of many types of machinery.

An interesting development in metal arc welding is the introduction of what are called 'contact' electrodes. These have an unusually heavy flux coating which contains such an amount of iron powder that the coating is conducting and the electrode is, therefore, self-starting when the coating touches the work. Because of the thick coating, the arc is shielded more effectively than with normal electrodes, and there is some directional effect which gives deeper penetration. Other advantages are that the welder is less fatigued than when using a normal electrode because with the latter he must hold a steady arc length, whereas, with the former, he need only rest the electrode on the work and keep the angle of inclination right; and also higher deposition rates are obtained than with other types of electrodes. These modern 'contact' electrodes, which were introduced in Holland immediately after the war, should not be confused with the older 'touch' electrodes (Class 5 coating) referred to earlier. The modern 'contact' electrode produces welds with a strength suitable for most requirements.

Another development in electrodes involving the use of a high proportion of iron powder in the coating is the so-called 'iron powder' or 'high recovery' type. The latter term originates from the fact that, due to the high proportion of iron powder in the coating, the amount of metal deposited (or the 'recovery') is 140 per cent or more of the metal in the core wire. Very high deposition rates are obtainable with this type of electrode.

Both the 'contact' and 'iron powder' or 'high recovery' electrodes have been adopted more readily and widely on the Continent and in the United States than in this country. In this case the conservatism and slowness to adopt new ideas of which we are often accused is not without justification. The high deposition rate obtainable with these electrodes is of great value but some doubts have been expressed as to whether the enthusiasm with which these electrodes were introduced and acclaimed were justified. However, when correctly used in suitable applications they have definite advantages, but some discretion is necessary in their use and application. Neither these nor any other type of electrode is the answer to all welding problems.

Another development which makes slow progress—largely it is believed because of difficulties over agreement on piece-work rates rather than for technical reasons—is the twin multiphase electrode. The process is one in which two electrodes are bound or formed together, and are operated on a two-phase supply fed from a 3/2 phase Scott connected transformer. With this arrangement arcing is always taking place between the work and one electrode or the other, and for this reason, ionization of the arc is continuously maintained. It is thus possible to use a much lower open circuit voltage and still to obtain very smooth welding and easy striking. This advantage has the very important effect that the power factor of the supply taken is correspondingly improved, since the power factor is approximately equal to the ratio of the arc voltage to the open circuit voltage. Figures as high as 0·65 have, in fact, been obtained. Another and major advantage is that a load is taken which is equally balanced on the three phases. An incidental advantage also is that with the lower open circuit voltage, the system is inherently safer from the point of view of shock risk. Furthermore, it

is claimed that higher welding speeds are achieved. In one particular case, 900 kW. seconds was required from a single-phase supply to weld a 5/16-inch fillet, 12 inches long in mild steel, as compared with only 770 kW. seconds for producing the same weld from a three-phase supply.

AUTOMATIC PROCESSES

Covered electrodes

Efforts are always being made to secure greater uniformity in welding and to secure a greater output per operator. The former advantage can be achieved by an automatic plant which has recently been introduced in Sweden, which uses normal arc welding electrodes. The machine has a magazine which is kept filled with normal electrodes, and these are automatically fed towards the work at a rate dependent upon the arc voltage. When the electrode is consumed, a second one takes over, the stub end being ejected. The device is said to work very satisfactorily, and clearly will give very uniform welding. It is not so obvious however that the output of such a plant would be in excess of that of a single skilled operator, though conceivably one operator could look after several machines. The more common method of doing automatic welding with covered electrodes is to form the electrode into a coil and to feed it continuously towards the work at a rate controlled again by the arc voltage. There are several machines of this type availalbe, the only fundamental differences between them being in the method of making electrical contact with the electrode. In some cases the electrode is specially wrapped with spiral wire, which protrudes through the coating and with which contact is made. In other cases the coating is removed on opposite sides of the diameter by a special cutter, and contact is made with the core wire through the slots thus created. Machines of these types are fairly common and are successfully used on many different kinds of work.

Submerged arc

In October, 1935, Jones, Kennedy and Rotermund filed a patent in the United States for an automatic welding process using a powdered or granulated flux and a bare welding wire. The patent is said to have arisen from the need for a method of welding a very long oil pipe-line. Something of a similar nature had been known before, but the type of flux used caused excessive generation of gases and moisture, and led to porous welds. The essential feature of the new patent was that the flux was chemically stable and when melted was conducting. Whether an actual arc is formed or not by this process, seems to be still undecided. Certainly the original inventors believed that they were providing resistance heating, and a recent private intimation from the Professor of Metallurgy in Moscow University confirmed this view; but the generic name to describe the process is submerged *arc* welding.

It is sufficient, however, to say that there is no visible arc, that the process permits the use of currents up to 5,000 amps and consequently the welding of thick plates with very few passes. A three-inch plate can be welded with a single pass. Excess of granulated flux flows over the weld preparation and combines

with that part which melts to provide an effective cover for the weld whilst it is cooling.

According to the original inventors, the desirable features of the flux are as follows:

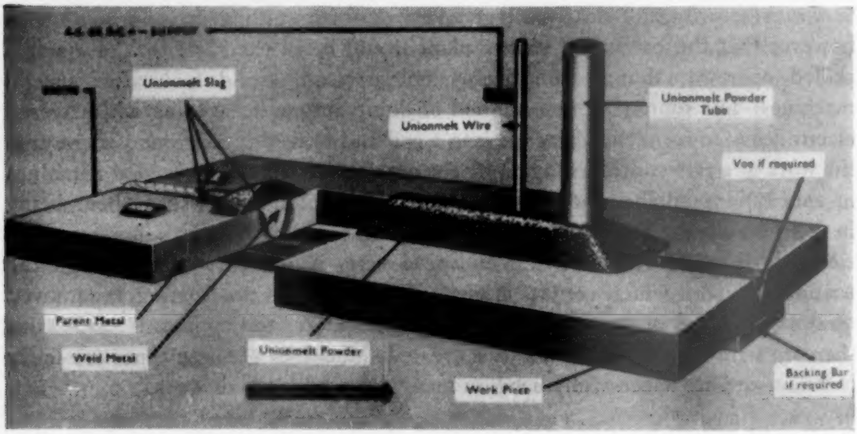
(1) The chemical reactions between the components of the welding flux must be completed before it is used in welding. Failure in this respect most surely invites porosity.

(2) It must be capable of controlling the penetration and the width of the weld.

(3) The fluidity at welding temperatures must be such that it will not become entrained with the molten metal.

(4) It must contain only chemicals which are not detrimental to the steel.

(5) It must be readily removable from the finished weld.



[By courtesy of Quasi-Arc, Ltd.

FIGURE 3. *The submerged arc welding process*

These results are apparently achieved with a flux which is made by firing together and granulating: 27 to 38 parts of lime; 9 to 16 parts of magnesium; sixty parts of silica; four to six per cent of alumina; and six per cent of calcium fluoride.

Table V gives the compositions of four different grades of flux available to-day from one supplier. With the exception of the fourth grade, where manganese dioxide replaces lime, magnesium oxide and alumina, it will be noted that there is comparatively little change in composition from the claims of the original patent. Some years after the first patent, Cohn filed one for a flux consisting of about sixty per cent alumina, forty per cent silica and 0·6 per cent of titania, and a small amount of sodium fluoride. This was processed at a high temperature but not vitrified. There are to-day a number of sources of supply of powdered flux, and different grades are used for different purposes. An interesting feature of this method of welding is that twice as much parent metal is melted as electrode

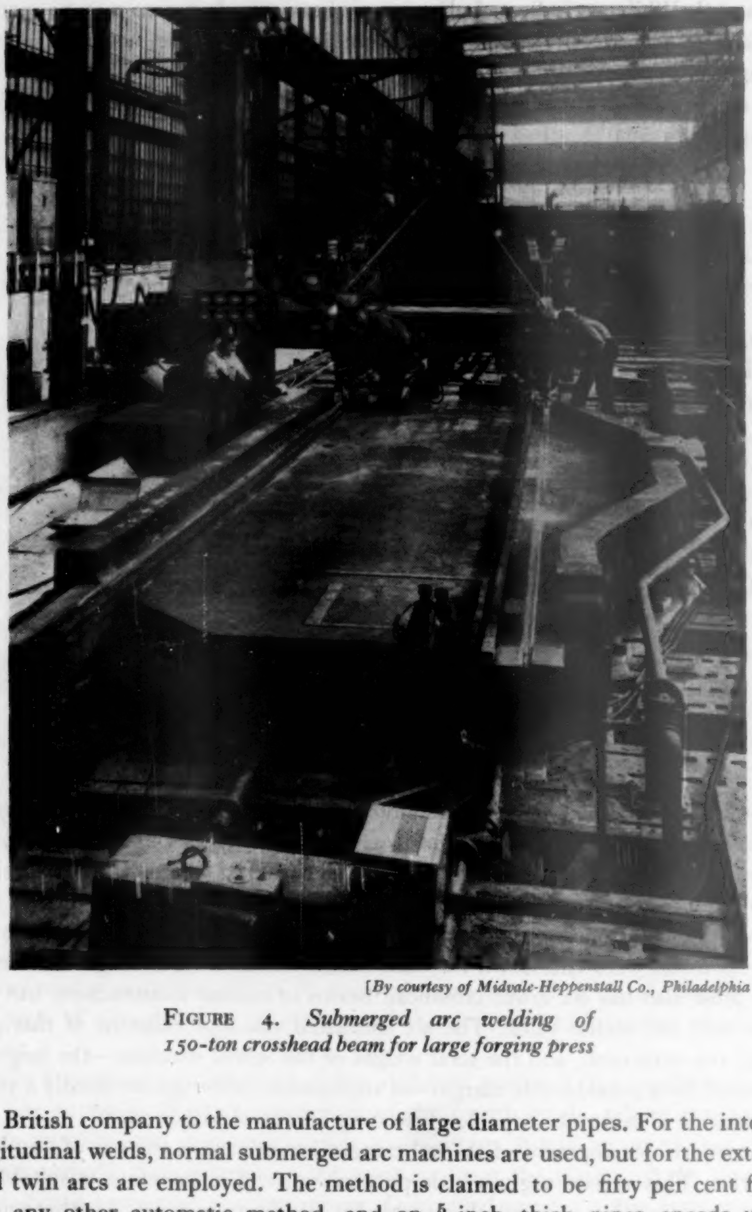
consumed. While, as indicated above, very heavy single passes may be made by the submerged arc process, such extreme thicknesses are not now popular. A very common operation, for example, is the welding of one-inch thick plate in a single pass at about ten inches per minute, using 1,500 amperes at an arc voltage of 38.

TABLE V. ANALYSIS RANGE OF UNIONMELT POWDERS

Grade	20	70	80	50
	%	%	%	%
CaO ...	24/29	25/31	23/26	4/6
CaF_2 ...	—	—	4·5/6	4/6·5
MgO ...	7/8	6/7	10/13	—
SiO_2 ...	50/57	45/50	37/39	40/43
Al_2O_3 ...	4/7	4/7	12/14	2/3
MnO ...	—	9/11	7/8	0·5/1·0
FeO ...	0·7 max.	0·7 max.	0·7 max.	—
TiO_2 ...	0·7 max.	0·7 max.	0·7 max.	—
B_2O_3 ...	0·05 max.	0·05 max.	0·05 max.	—
Pb ...	0·005 max.	0·005 max.	0·005 max.	—
Fe_2O_3 ...	—	—	—	1/3
S ...	0·04 max.	0·04 max.	0·04 max.	—
MnO_2 ...	—	—	—	39/40
BaO ...	—	—	—	2·0 max.

An unusual application of submerged arc welding occurred in the recent manufacture in the United States of a 50,000 ton Loewy forging press. The six upper crosshead beams for this press weighed 150 tons each, and the joining of the web to the flanges involved welds in material no less than 12 inches thick (Figure 4). The successful accomplishment of this task in which over two tons of weld metal were laid down for each beam, was an outstanding achievement. The press also has six lower crosshead beams of similar construction, but with webs only ten inches thick. The six laminated 100-foot columns of this press weigh 100 tons each, and the total weight of the whole machine—the largest in the world by a considerable margin—is 10,000 tons. Although nominally a 50,000 ton press, it is said to be capable of exerting a force of 61,000 tons.

A modern development of the submerged arc process is the use of two heads in series. This variation gives little penetration, and is therefore unsuitable for normal welding, but particularly suitable for cladding processes. Another modern development is the use of two separate heads with separate power supplies but operating within a few inches of one another. Figure 5 shows an example of this, and it is interesting to note that with one application on half-inch plate, a speed of 14 inches per minute was achieved with a single head, but with two heads the speed increased to 32 inches per minute. This method has recently been applied



[By courtesy of Midvale-Heppenstall Co., Philadelphia

FIGURE 4. *Submerged arc welding of 150-ton crosshead beam for large forging press*

by a British company to the manufacture of large diameter pipes. For the internal longitudinal welds, normal submerged arc machines are used, but for the external weld twin arcs are employed. The method is claimed to be fifty per cent faster than any other automatic method, and on $\frac{5}{8}$-inch thick pipes speeds up to 36 inches per minute have been obtained.

Yet another variation of submerged arc welding is the semi-automatic process in which an electrode gun is held in the hand. A continuous coiled electrode is used and fed through a flexible cable to the hand gun. The melt is supplied through an inverted conical container on the gun or, alternatively, through a large

flexible tube which carries also the electrode. Current connection to the electrode is made in the gun through sliding contacts. The arc length is maintained uniform in the usual way, and for this reason the control required by the operator is less than with hand welding. There is, however, the disadvantage that he is not normally able to see the line on which he is welding, due to the presence of the powdered flux, and this causes considerable difficulty unless the work is of a type which can be rotated. It is, therefore, generally felt in the industry that the scope for this semi-automatic device is somewhat limited.

[By courtesy of South Durham Iron & Steel Co., Ltd.

FIGURE 5. *Twin arcs for submerged arc welding of pipes*

It is interesting to note that the Russians make good use of submerged arc welding and have even applied it to the welding of thick aluminium—a practice which is unknown in this country. Another interesting Russian development relates to the welding head. This normally controls the speed of the wire so that the arc voltage is a constant. If the arc voltage deviates from normal, the feed speed is altered so as to restore the proper value. This is the normal practice with British and American machines, but it is much more common in Russia to use a head which feeds the wire forward at a constant speed. This speed has a continuous or stepped variable control but, once set, the speed of the wire does not change.

The ability to operate at a constant speed was an important discovery and is said to have had a large influence on the introduction of automatic welding in

the U.S.S.R. It will be appreciated that the current from the normal welding generator increases as the arc length decreases and, provided the wire feed speed is approximately correct, the arc length becomes self-adjusting so that the burn-off rate is equal to the feed rate. It is unlikely that the response would be sufficiently quick to satisfy hand welding, but with the steadier operating conditions of automatic welding, it becomes quite feasible.

ARGON ARC WELDING

The need to shield the welding arc, the hot pool of molten metal, and the adjacent hot metal from the surrounding air, was realized quite early in the present century, but curiously enough the most direct method of doing this, namely to shield the hot parts with a separately supplied gas, was not introduced until some thirty years later. As has already been explained, the method of effecting this shielding with a metal electrode is to provide a coating which vaporizes in the heat of the arc and provides the shielding gases. The more direct method was introduced in the early 1940s, when an American aircraft company used the inert gas helium when welding thin gauges of magnesium and stainless steel sheet. The heat for welding was supplied by an electric arc maintained between the work and a tungsten electrode held in a special holder or torch. Helium gas was passed through the handle of the torch to a nozzle surrounding the tungsten electrode where it flowed over the hot electrode and molten pool protecting them both from oxidation by the atmosphere.

This process is made possible by the fact that the tungsten electrode, although melted at the tip, is consumed only very slowly. Alternative electrodes have been used, such as carbon and molybdenum, but these are quite exceptional and practically all the work is done with a tungsten electrode of which there are at least two varieties, one consisting of plain tungsten, and the other tungsten with a small percentage of thorium to give superior electronic emission characteristics. The high heat input, absence of flux, and the suitability for mechanization, attracted considerable attention to the process. The original method used a direct current arc and was confined to the welding of magnesium alloys and stainless steel. Later a superimposed high frequency spark was used to facilitate the striking of the arc. Within a few years, high purity argon had been used to a large extent to replace helium for manual welding, and direct current had given place to alternating current as the power supply, and many other materials had been welded.

The process is used with particular success for welding aluminium alloys where the absence of flux gives greater scope to the engineer, since fillet welds, and other types of joint in which flux might be trapped, can be safely employed. Excellent weld strengths are also obtained, partly as a result of the increased welding speeds. In this country helium arc welding is practically never used due to the unavailability of helium. Argon arc welding is used for butt, edge, lap and fillet welds in a wide range of thicknesses. It is essentially a method of producing high-quality welds and, although it is at its best when used in the down-hand position, it is possible with skill to make welds in all positions.

Being an arc welding process, the welding heat is concentrated and the heat-affected zone is limited. Distortion is less than with gas welding. Thick material and intricate parts can all be welded satisfactorily, advantages of particular importance in the fabrication of chemical plant and equipment for the aircraft and aircraft engine industries. Although the method may be used for quite thick material, it is generally found that other processes are more economical.

Alternating current is most commonly used for argon arc welding, but it is also possible to use direct current with the electrode either positive or negative. The electrode positive is used sometimes for materials with a tough oxide film, such as aluminium or magnesium, but the electrode becomes overheated at quite low currents, and the use of this arc is therefore limited. Electrode negative arcs are used more often, but only for welding materials where the oxide film is readily broken down or dispersed, such as copper-base alloys, stainless steel and mild steel. When the electrode is negative, it does not become so hot and very high currents can be used. The A.C. arc must be used for all high current welding of materials with refractory oxides, because in argon arc welding the arc has two functions to perform, the supply of heat and the removal of oxide from the edges of the joint. With other welding processes, oxide removal is generally accomplished by a flux or by the atmosphere over the welding pool. In the argon arc process, the oxide surface is removed by an action, partly physical and partly mechanical, which occurs only when the electrode is positive. The A.C. arc therefore combines the advantages of oxide removal when the electrode is positive with the cool running of a negative polarity electrode. The use of A.C., however, introduces difficulties, and special devices are required to start and maintain the arc.

When the electrode is negative, the arc burns satisfactorily, but when the voltage is reversed so that the electrode becomes positive the arc goes out and will not re-ignite unless at that instant there is sufficient voltage available at the transformer. The voltage necessary to cause re-ignition of the electrode negative/positive change varies according to the material being welded and the characteristics of the transformer. With some types of transformer, dangerously high open-circuit voltages would be required for welding aluminium. This danger can be avoided by using a special device to inject the necessary high voltage at the critical moment of the change-over from negative to positive. This can be done by what is known as a high-frequency ionizer, but this device causes radio interference which may be a source of considerable trouble.

As an alternative, use may be made of the Electrical Research Association's surge-injector unit. This device injects a single pulse of moderately high voltage direct current timed accurately for the period when no current is flowing. The arc is ignited directly in a manner which does not cause radio interference, and welding transformers can be used with open-circuit voltages lower than is possible when a spark ionizer is employed. Figure 6 shows the cross-section of an air-cooled and water-cooled torch in essential details. The argon gas is directed on to the weld pool through a ceramic or water-cooled metal nozzle. Formerly

ceramic nozzles were used for all work, but with high currents they are unsatisfactory because of the rapid heating and cooling which causes them to crack. Metal nozzles are, therefore, preferable for all work over 100 amperes. They give greater economy in argon, and better accessibility because a smaller diameter nozzle can be employed

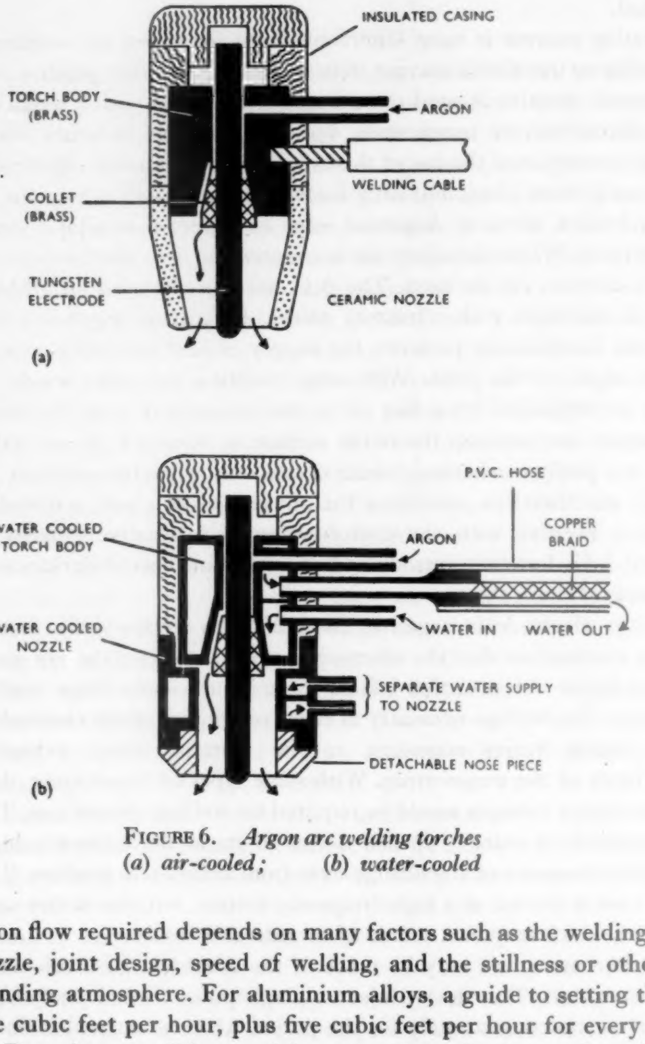


FIGURE 6. *Argon arc welding torches*
(*a*) *air-cooled;* (*b*) *water-cooled*

The argon flow required depends on many factors such as the welding current, size of nozzle, joint design, speed of welding, and the stillness or otherwise of the surrounding atmosphere. For aluminium alloys, a guide to setting the argon flow is five cubic feet per hour, plus five cubic feet per hour for every hundred amperes. Draughty conditions might necessitate having twice this flow. Unprepared butt welds are popular in argon arc welding, since no additional metal need be added, but where the thickness becomes too great for this, then clearly filler metal must be provided. The composition of the filler may be used to control the metallurgical quality of the weld, to prevent cracking or to increase

strength. For example, aluminium magnesium alloys, low in magnesium, are often welded with filler rods having a higher magnesium content, the purpose of which is to give greater resistance to cracking and higher weld strength.

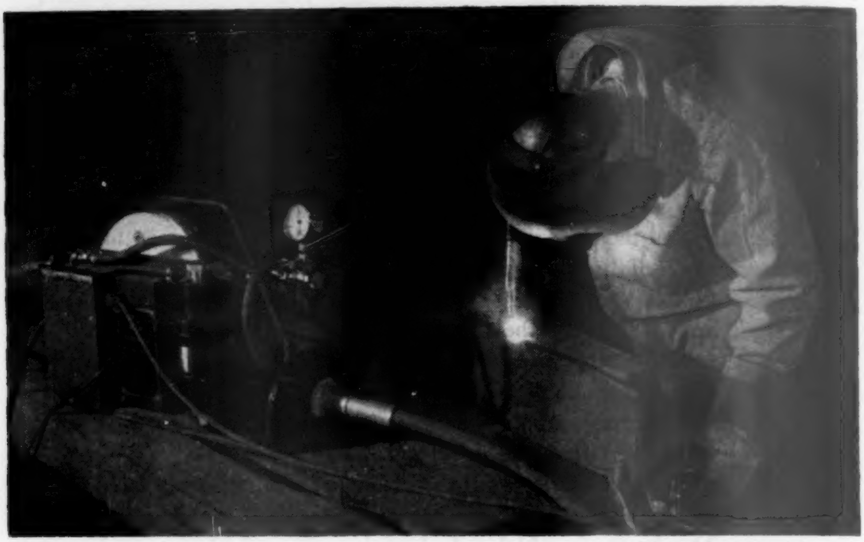
It is very difficult to obtain precise comparisons of the relative cost of argon arc welding and metal arc welding, but arguments on this subject, which were quite prolific in the early days, are of less significance now. For one thing, the argon arc process is cheaper than it used to be owing to considerable reductions in the cost of argon, the chief item of expense, but another reason is that there is seldom a great deal of dispute as to which is the more appropriate method to use. In some cases, metal arc welding is obviously desirable, in others, it is essential to use argon arc welding and the fringe field between the two is a small one. Thus the question of economics does not so often arise as might be expected. It is, however, always desirable that economy should be exercized in the use of argon, and for this reason argon-economizers are fitted which turn off the gas shortly after the current supply is interrupted.

The process is particularly suitable for automatic welding, and there are some quite striking applications. One in particular is the automatic welding of aluminium cable sheaths in which a dual arc is used, and where very long runs must be done with perfection, otherwise valuable lengths of cable would be destroyed. As much as 1,000 yards involving about nine hours of continuous welding has been done without stopping. The process of argon arc welding has considerable application in the manufacture of gas turbines and jet engines, partly because of the difficulty of otherwise welding the materials which are used, but also because it is possible to obtain a very precise control: very highly satisfactory welds are produced which not only look well, but give consistently reliable quality.

Inert gas shielded metal arc welding

Reference was made earlier to the fact that the first method thought of for shielding the weld from the atmosphere was to put a coating on the metal electrode which, when melted and vaporized, provided the shielding gas. It was then some thirty years before the argon arc process was introduced in which a shielding gas was deliberately supplied, and the electrode was non-consumable. After a further interval of five to ten years, these two processes were combined by a most important invention in America. In this, a consumable electrode is used with argon gas-shielding. The process as applied to hand electrodes of the usual type would obviously be difficult to use though, in fact, some attempt has occasionally been made by supplying gas separately through a jet and shrouding the end of the electrode. The new process is one in which the electrode is consumed at a very high rate. It is no longer a stick electrode; it is a coil of wire which is fed through a torch at the end of which it is consumed by the arc. The gas is supplied through the torch in much the same way as with the argon arc torch. This was a highly significant introduction, and gives all the combined advantages of gas shielding with a bare electrode.

Theoretically, the method might be possible with a consumable electrode



[By courtesy of Quasi-Arc, Ltd.

FIGURE 7. *A self-adjusting arc welding set*

which was fed slowly, and burnt off much in the same way as with ordinary automatic welding, but in fact the invention combined two features—not only the shielding of a bare wire with a separately supplied gas, but also the use of an exceptionally high current density which results in what is known as the self-adjusting characteristic of the arc. The principle of self adjustment depends to a great extent on the power source which supplies the welding current. This means that, although the filler wire electrode is fed at a constant pre-set speed, the welder cannot alter the arc length by moving the torch. An attempt to shorten the arc, for example, is corrected because the shorter arc draws more current from the circuit and this increases the burn-off rate, thereby bringing the arc back to its equilibrium length.

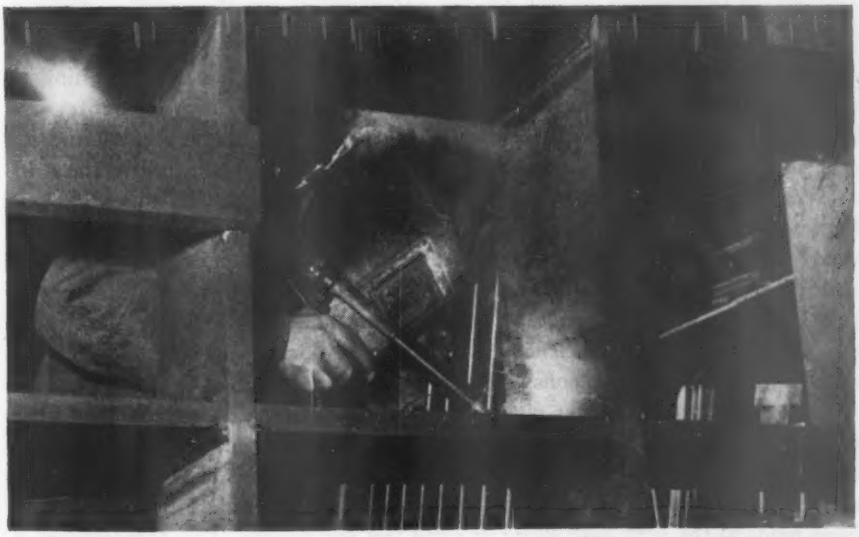
The introduction of the process in America was of the very greatest significance, and machines have now been produced in this country also for a few years. The process is described by various trade names, such as Aircomatic welding, Sigma welding, Argonaut welding, but a generic term which is more suitable, is self-adjusting arc welding. Figure 7 shows the general arrangement of the equipment; the wire is provided on a drum and is fed through a pair of driving rolls which force it at a speed of up to 500 inches per minute, through a flexible tube to the nozzle. This tube may also carry the power supply and the shielding gas. Everything terminates in the nozzle operated by the welder, and the process of operation is a particularly simple one which can be learnt far more easily than ordinary metal arc welding.

The process is used for the welding of light alloys, stainless steel, a number of other non-ferrous alloys, and has recently been applied to the welding of mild

steel, an illustration of which is shown in Figure 8. Whilst in the early days of the process argon was the sole shielding gas used, there have now been various modifications in which argon is mixed with oxygen, and sometimes carbon dioxide is used, according to the type of material being welded. The prospects for this equipment in the future are very large; it is becoming increasingly popular, and undoubtedly leads to good quality welding at a much higher rate than is possible with any other method. It should be said, however, that to get the best results it is desirable that special types of power source should be used for the purpose, and extensive co-operative research work between the Electrical Research Association and the British Welding Research Association has led to recommendations involving power sources of quite different characteristics from those generally used for metal arc welding. These characteristics are such as to reduce the open circuit voltage, and to lead to much greater stability in welding.

Naturally, commercial developments follow slowly on research, but it is quite evident that the introduction of this new process has led to new and quite original thought on the types of power source required for welding circuits, and it may well be anticipated that not only will this lead to changes in the type of power supply used for the self-adjusting arc welding, but may well react on the type used for other kinds of welding.

It would be unwise, indeed incorrect, to suggest that this new method of welding is substantially displacing metal arc welding. This simple and relatively cheap method of welding is likely to be the principal method used for very many years in the future, but there is no doubt that the introduction of self-adjusting



[By courtesy of Morfax Ltd. and Scope

FIGURE 8. *Welding a mild steel structure by the self-adjusting arc process*

arc welding has great possibilities, and is steadily finding increasing use. At the moment, the cost of equipment is high, and the method is perhaps only justified where high production rates are required. There is undoubtedly much development work yet to be done, particularly in the direction of improving the quality of the welds which are somewhat liable to porosity, but the process should be watched by all interested, very carefully, for there is little doubt that this introduction is quite as important in the welding field as was the introduction early in the century of covered electrodes to replace bare wire.

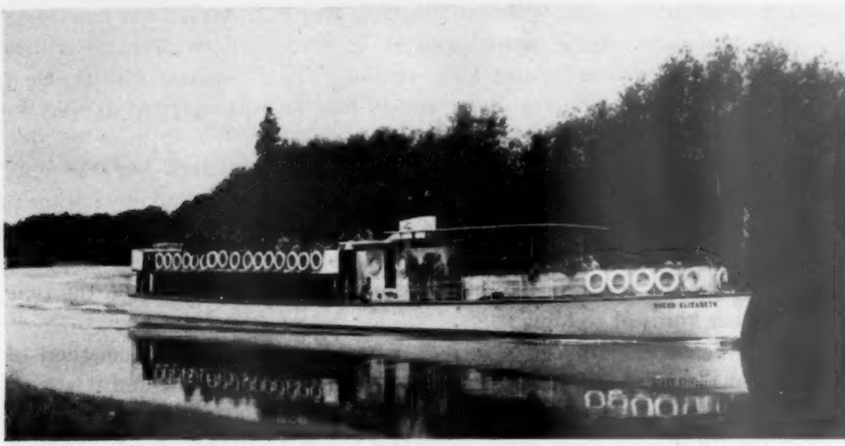


FIGURE 9. *The* Queen Elizabeth—*aluminium superstructure welded by the self-adjusting arc process*

The process is particularly suitable for aluminium, and it is interesting to record that the first large-scale application to this material in this country was done by the British Welding Research Association when the superstructure for a small Thames pleasure-cruiser was welded in the open air, using the self-adjusting arc process. This was done in the year 1952, and was entirely satisfactory (Figure 9). Since then, the process has been used on another and much larger vessel, the *Morag Mohr*, which is a yacht of 45 tons displacement, fabricated from aluminium magnesium alloy. There is a steadily increasing interest in the use of aluminium for the superstructures of ships, and there is little doubt that, where the weather conditions are not too unfavourable, this new method of self-adjusting arc welding has considerable application.

There is at present under construction in a British yard a 20,000 ton liner for Norway, the *Bergensfjord*, where this method has been widely used for the aluminium superstructure. This structure contains 300 tons of aluminium alloy, and both hand and controlled arc welding are being used. Fillet welds have been made at the very high speed of eight feet per minute. The *Manicouagen* is another vessel having a welded aluminium superstructure which has been recently built in this country.

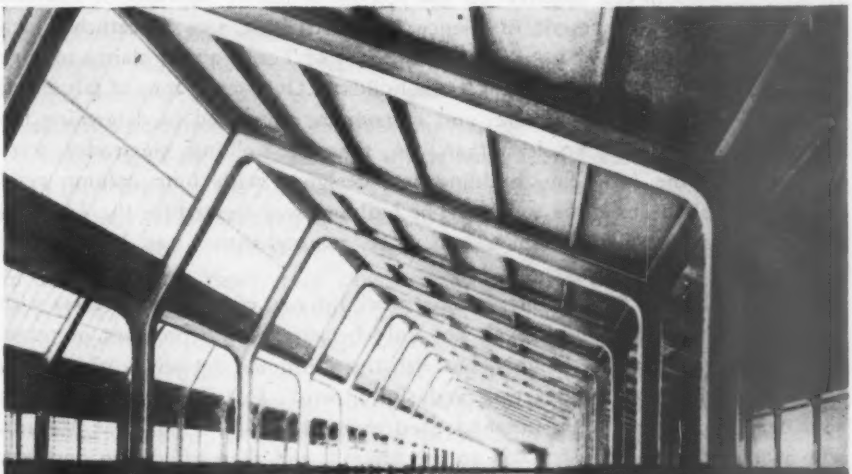
LECTURE II

Monday, 23rd April, 1956

APPLICATIONS OF WELDING

Structural steelwork

One of the most important applications of welding, and one which has made very great strides since the war, is the application to structural steelwork. This includes bridges, buildings, tanks of various kinds, cranes, and other types of construction. In the case of buildings, welding is particularly applicable to factories, where a very great improvement in appearance can be effected by using welding in the place of riveting (Figure 10). The clean lines which arise from a welded structure are quite striking and immediately apparent on entering a factory; not only is this an advantage from the point of view of appearance, but it means cheaper maintenance, since cleaning and painting are made less costly by the absence of rivet heads. Also there is less dust and moisture on the steelwork, because of the smoother surfaces, and corrosion problems are minimized. Most important of all is the fact that, with the use of welding, considerable economy can be effected in the weight of steel used, which is important in times of steel shortage, but this can also result in a reduction in cost, though, in fact, there was some difficulty in the early days due to some contractors placing a higher price on welding construction than on riveting construction, just because they were inexperienced and wished to continue in the old way.



[*By courtesy of Murex Welding Processes Ltd.*

FIGURE 10. *Welded steel frame factory building; Austins, Cleveland, Ohio*

One other advantage of welded construction is that construction is a very much more silent operation than with a riveted building, and for this reason extensions to hospitals may advantageously be welded. It is interesting to note that the rapid extension of office and factory buildings in Houston, Texas, has been done by welding, largely to minimize the noise nuisance.

A typical example of a welded factory building is that of the new mill building for Bairnswear Limited, Worksop. The framework is of continuous monitor form, designed as a portal frame structure consisting of three sixty-foot spans with the outside legs of the frames pinned at their bases. The overall width of the building is 180 feet with a length of 380 feet: maximum height from the floor level to the general roof is 21 feet.

Another example of welded structures is the I.C.I. Tube Mills of Kirkby. This all-welded single-storey factory building comprises two bays, ninety feet wide and 1,500 feet long, with a clear height to the eaves of thirty feet. Adjacent is a single-storey flat roof bay, thirty feet wide and 18 feet high, running almost the full length of the main building. The total weight of steelwork amounts to 4,000 tons. The main frames of the double bay building at thirty-foot centres are completely welded. The vertical legs are 30-inch by 12-inch H sections; each is built up from a 20-inch by 12-inch broad flange beam with a 10-inch by $\frac{5}{8}$-inch plate inserted in the centre of the web. The rafters also of H section have a profile tapering from 25 inches deep at the bottom of the roof slope to 14 inches deep at the ridge. These are also made up from a 20-inch by 12-inch broad flange beam section in which the webs are cut diagonally, the pieces reversed, and the webs butt-welded together. An early example of the use of welding in constructional work in this country was the reconstruction of the Bank of England where, no doubt, the merit of silence of construction was a feature which influenced the decision to use welding. The city of Toronto now claims to have the world's largest all-welded steel frame building. Over 5,000 tons of fabricated steel were used in the structure, and ultrasonics were used to determine the soundness of welds. No less than ten tons of welding electrodes were consumed on the job. The building was designed with four column rigid frames with all beam joints welded. The building was erected for the Imperial Oil Ltd., and possesses a floor area of nearly 300,000 square feet. It is 290 feet high.

As is well known, in all constructional work the cost of the job increases with the elevation above ground level, not only because of the problem of transporting things to greater heights, but also the additional danger to which men are exposed involves greater care and slower work. For this reason, there is considerable interest in the method used to erect airport hangars at Madrid. The whole roof was constructed on the ground, and then lifted into position. This method of construction has been used a number of times in Spain, and has considerable merit. One of the hangars is 154 feet wide and nearly 600 feet long. The total weight of the roof is 450 tons, which represents no mean achievement in erection practice.

It had long been suspected that the rule-of-thumb methods used for the

design of steel frameworks were based on assumptions very far from the truth. The need to investigate the position led to the setting up of the Steels Structure Research Committee in 1930, and for many years careful research was carried out to discover the true situation. Experiments were made on the Cumberland Hotel and on the Geological Museum whilst the buildings were under construction, and they confirmed the suspicions that assumptions were far from the truth. Arising from all this work, a rational method of design in the elastic range was devised but, unfortunately, it was somewhat difficult to apply, and whilst it was in fact rational and led to the stiffening up of some members and to reducing the dimensions of others, the final result did not represent a very great economy in steel. As a result, the industry stuck to its old methods and, to some extent, the work of seven years' research was virtually thrown away. However, the principal investigator, Professor J. F. Baker, then turned his attention to a much more profitable line of research, namely, a study of the behaviour of structures when the steel is stressed into the plastic range. The old method of design was based on the assumption that the maximum stress at any point in the framework did not exceed the yield point of the material. The plastic design method is based on the assumption that at some multiple of the maximum working load on the building the structure will completely collapse. This is, after all, a much more rational approach than the old method, and it is a method which leads to appreciable economy. Plastic design, which is the name by which the method is known, is only applicable to truly rigid structures, that is structures which are made by welding. It is also important to note that structures which were indeterminate by elastic methods of design can be completely solved by plastic design methods and all the members therefore economically dimensioned.

Professor Baker has been working at Cambridge with a team of assistants on this subject for about ten years with the support of the British Welding Research Association, which naturally has considerable interest in such a method of design. Full-scale experiments which have been conducted have, in fact, been carried out at the Association's own Research Station at Abington. It was perhaps inevitable that the acceptance of such a revolutionary method of design has proved to be somewhat slow. There is, however, considerable interest and, in the last two or three years, practical application is by no means negligible. In fact to-day there are something like 200 buildings, or even more, which have been constructed using the plastic design method. There is still much research to be done, particularly on multi-storey buildings, in order that the ultimate efficiency may be achieved, but in general terms it may be said that by the use of plastic design up to as much as 25 per cent of the weight of the steelwork may be saved, as compared with normal riveted construction. It is interesting to record that, although this research work has been consistently published, it has so far not been applied in the United States to anything like the extent that it has been in this country. Americans admit our leadership in this field, both in the theory of the method and in its practical application. One of the first buildings in this country to be constructed by this method was the Fatigue

Laboratory of the British Welding Research Association at Abington, near Cambridge. This building was erected in 1952.

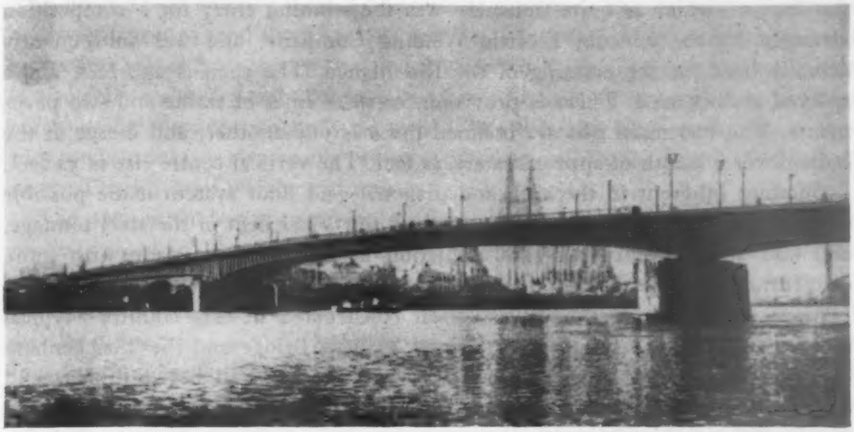
An important application of this method of design is to the stores buildings for the Admiralty which have been erected at Rosyth and elsewhere. Another important building is the transit shed for passengers and cargo at Southampton which was also designed by the plastic method.

Welding is also being used in the construction of frameworks for some of the new power stations built by the Central Electricity Authority. For these stations very heavy steelwork is required, since not only is it necessary to support cranes capable of lifting the heaviest parts of machinery, but also it is the practice to-day to hang the boilers from large girders, as distinct from the old practice which was to stand them on the floor. This extra heavy type of construction has led to the introduction of rectangular box section stanchions as the main supports. These stanchions, which are built up from flat plates which are several inches thick, are made by welding the plates together at the corners. Automatic welding is naturally used for such a purpose. Box section portal frames, built up from plates, are also being used for the turbine house. The clean lines and smooth surfaces with this type of construction not only give a pleasing effect, but also reduce the maintenance costs.

A big advance in welded structures was made a few years ago when it was decided to use welding for the structural work of the various shops of the Margam Steelworks. The smallest of the three operational shops was the mould preparation bay: this is 97 feet wide and 880 feet long, and has continuous welded crane girders for the full length. The melting shop had the heaviest crane girders. These were 110 feet long between supports—to suit the spacing between steel furnaces—and 12 feet 9 inches deep to suit the 300-ton capacity cranes on the casting bay side. The flange plates varied from 36 inches by 2½ inches to 36 inches by 4 inches, and were welded to flitch plates 2 inches to 3 inches thick and 19 to 24 inches deep. The flitch plates were welded to a one-inch thick web plate. The complete girder weighed slightly under a ton per foot of length. The joining of girders to one another was carried out by five welders working simultaneously, and the average time required to complete a joint was 37 man-hours, working continuously.

Bridges

The use of welding for bridges is all-important, and has made greater progress on the Continent than in this country. Some very fine examples can be named as, for example, the Duisberg all-welded by-pass road bridge. This is made up of three spans of 130 feet each, and four centre spans of 33 feet and 44 feet. Another example is the Rugendamm Railway Bridge. This consists of 12 spans of 202 feet long, five spans of 177 feet and five spans of 170 feet. The longest spans weigh just over 100 tons each. Other examples are the Schooten Bridge over the Albert Canal, Belgium, and the Pilsen Bridge, Czechoslovakia. It is interesting to note in this case that the tender for the welded bridge was accepted in competition with several tenders for riveted alternatives, because of the

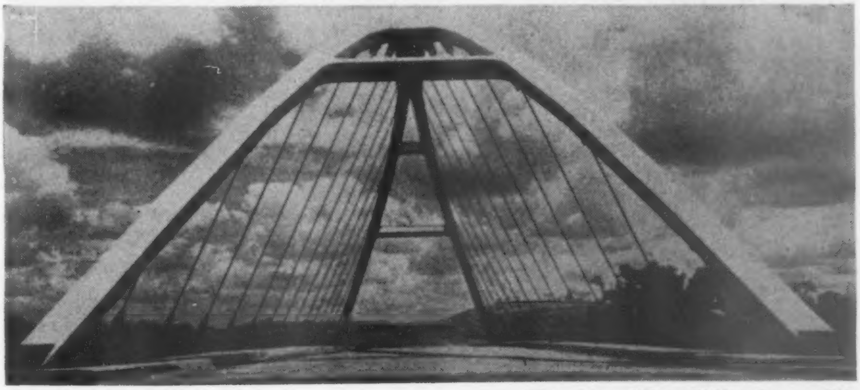


[By courtesy of Murex Welding Processes, Ltd.

FIGURE 11. *Welded bridge over the Rhine at Cologne*

lighter weight and lower cost of the welded design. Very considerable use of welding for bridges was made by the Germans in the construction of foot bridges and road bridges over their ***Autobahnen.*** A fine example of welding is the new Cologne Bridge over the Rhine (Figure 11). This bridge is 68 feet wide, made up of a 38-foot roadway having two tram tracks, two cycle tracks of five feet each, and two pavements of ten feet each. The total span of the bridge is 1,434 feet over two piers: the lengths of the individual spans being 433 feet and 397 feet for the shore spans, and 604 feet for the central span. The shore span slopes towards the centre at 2·8 per cent. The total weight of the bridge is 5,669 tons. It replaced an old suspension bridge weighing over 8,000 tons.

An interesting example from America is the bridge over the Rio Blanco near Vera Cruz (Figure 12). The interesting feature about this bridge is that



[By courtesy of Murex Welding Processes Ltd.

FIGURE 12. *Welded bridge over the Rio Blanco, Vera Cruz*

the design—which is quite unusual—was the winning entry for a competition arranged by the Lincoln Electric Welding Company, and was subsequently actually used for the crossing of the Rio Blanco. The span is 250 feet, and a splayed arch is used. There is provision for three lines of traffic and two pavements. The two main ribs are inclined towards one another, and merge at the crown over a length of approximately 32 feet. The vertical centre rise is 52 feet. Economies inherent in the arch and diagonal grid floor system made possible weight reductions amounting to as much as thirty per cent of the steel tonnage, and also about twenty per cent reduction in cost in comparison with more conventional bridge designs.

Many welded bridges have also been constructed in this country—typical recent examples being the Stewarts Road Railway Bridge and the Twickenham fly-over. Other interesting cases are the seven bridges, all between sixty and seventy feet long, built to replace others washed away by flooding of the River Eye in Berwickshire in 1948. Contractors were invited to submit tenders for either riveted or welded bridges. Of the six tenders received, all the main items showed a lower cost per ton of steelwork for the welded design than for the riveted design. As, in addition, the former was about twenty per cent lighter than the latter, the choice was simple. The cost saving for one of the bridges by using welding was 16 per cent and, for the remaining six, 27 per cent.

Tubular steelwork

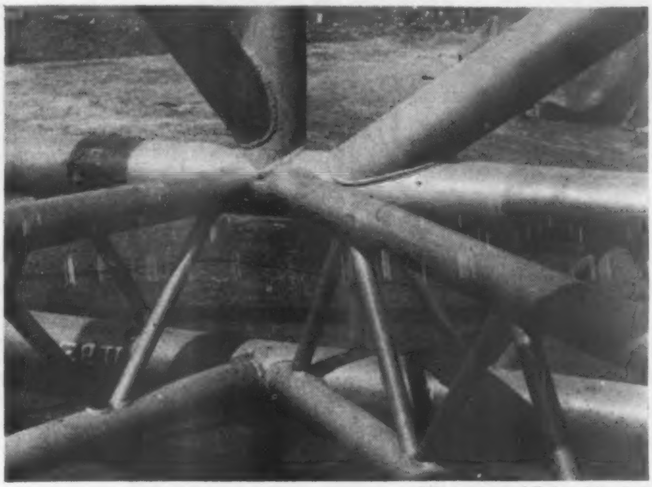
An interesting and important modern development is the use of welded tubular construction. An application which has become very well known is the jib of the biggest walking drag-line in the world. This was built for Messrs. Stewarts & Lloyds, and is used at one of their iron ore mines for removing the 100 feet thickness of overburden below which the iron ore is buried (Figure 13).

[*By courtesy of Tubewrights Ltd.*

FIGURE 13. *The world's largest walking drag-line excavator*

The jib is made entirely from tubes welded together. The complete excavator weighs 1,600 tons, and the jib is 282 feet long. In its working position, its head is five feet higher from the ground than Nelson's column. The drag bucket, which is also fully welded, weighs 26 tons and has a capacity of twenty cubic yards of earth—weighing approximately 27 tons. Thus the total load on the jib is over fifty tons, and this is slewed at a radius of 260 feet—nearly the length of a football pitch. The jib itself weighs 126 tons.

The two main boom members were made from twin tubes with distance pieces welded in. By this means it was possible to adjust the size of the tube to suit the stress, and to change from one size to another by means of taper tubes. The maximum diameter of tube used in the booms was 16 inches. The material for the tubes was a low alloy chromium-molybdenum steel, and a half per cent molybdenum steel electrode was used for welding. No less than two tons of electrodes were required, numbering some 18,000, and two men did all the welding. All critical welds were inspected radiographically, and a few defects were found and rectified.



[*By courtesy of Tubewrights Ltd.*

FIGURE 14. *Complicated tube intersections on excavator jib*

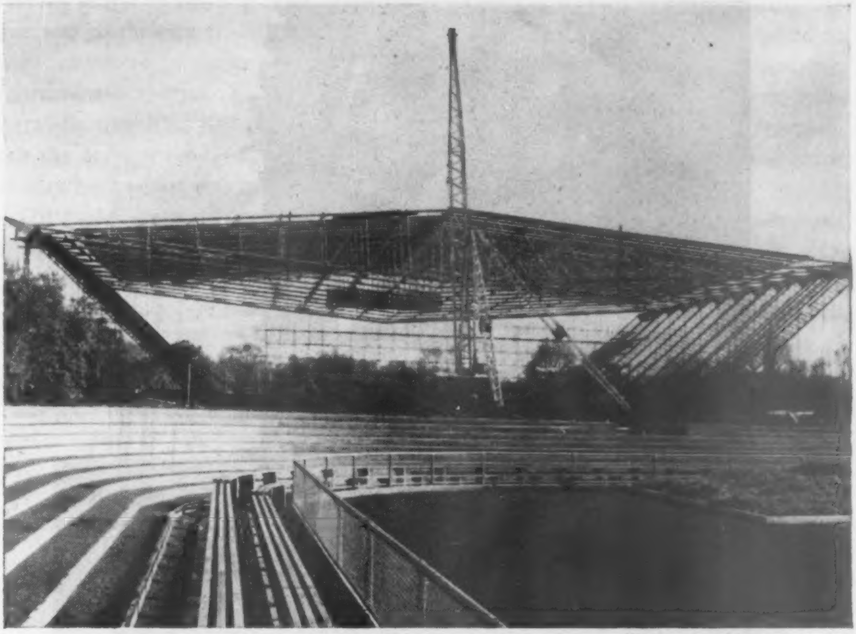
Pre-heating to 160°C. was used for all welds, and owing to the adverse conditions which sometimes occurred when doing this work in the open air, asbestos blankets were used around the weld and placed over the weld to slow the cooling rate. Great skill was required in the preparation of the tubes to ensure the correct angle between the surfaces to be welded together. The joining of tubes by butt and fillet welds always requires special care, but the complication of this job was exceptional because in many places several tubes of different sizes meet at a point—and all are highly stressed (Figure 14). This situation seldom arises in pressure pipework where, although the angles may present similar preparation difficulties, it is seldom that more than two pipes meet at a point.

Another outstanding modern achievement, made possible by welding and the use of tubes, is the National Coal Board sea boring unit (Figure 15). This is a structure which makes it possible to bore trial holes below the sea in order to search for coal seams—many of which surround the coast. The unit was built on the shore and floated into place on pontoons. It can be moved from one site to another, and is completely self-contained with power supply, drilling gear, lifting tackle and living accommodation comprising no less than 25 bedrooms (all with hot and cold water supplies), mess rooms, a cooks' galley, and other amenities.

[By courtesy of Tubewrights Ltd.

FIGURE 15. *National Coal Board sea-boring unit—welded tubular construction*

A special feature of this construction is once again the multi-branch connections of which there are 24, where from four to ten tubes meet and are welded together. In some cases, the tubes have to be tapered to fit into the cluster. In the case of the sea boring unit, it was possible to do much of the difficult welding in the works since the unit had to be demountable so that it could be transferred to a distant site if necessary. Tubes up to 24 inches in diameter are used. The tower is designed for boring in a sea-way up to a depth of 120 feet, and can withstand an eighty mile an hour gale and thirty-foot waves. It is an exceptional British engineering achievement worthy to take its place beside the Forth Bridge near to which it was built and first used.



[By courtesy of Tubewrights Ltd.

FIGURE 16. *Olympic swimming pool, Melbourne. Welded tubular steel construction*

Another interesting application of welded tubular structure is the swimming pool specially constructed for the Olympic games at Melbourne (Figure 16),

In all kinds of transport, whether by road, rail, air or sea, welding fulfils an important *rôle*. In the case of cars, resistance welding is mostly used, but there is also some application of gas welding. In the case of lorries, some arc welding is used, and particularly for road tankers. These are used for conveying all sorts of liquids such as milk, beer, petrol and chemicals, and the vessels are to-day invariably welded. With aircraft, so far as the frames are concerned, welding is mostly of the resistance type. Arc welding of various kinds is, however, used in connection with the engines.

The most important application of welding in connection with transport is the welding of ships. In 1918 a 275-ton welded barge was constructed in this country for cross-channel service. This was the first use of welding in the construction of a sea-going vessel. The hull was rectangular in cross section amidships with only bilge plates curved. Plating was $\frac{1}{4}$ inch and $\frac{5}{16}$ inch thick, and all the joints were lap welded. At the time, this was generally thought to be the first application of welding to a vessel, but it was subsequently revealed that a welded boat had been in use on Lake Erie for a number of years. This was called the *Dorothy M. Geary*, and was built by its owner, Mr. Frank Geary of the Geary Boiler Works, Ashtabula, Ohio. The keel frames and deck house

[*By courtesy of Shell Photographic Unit*

FIGURE 17. *A 17-ton pre-fabricated section bulkhead being lowered into place on a tanker*

of this boat were riveted, but the seams of the hull and the fore and aft deck plates were all electrically butt welded. The coaster *Fullagar* was the first all-welded ship to be built under Lloyd's survey. She had a dead weight of 500 tons, was built by Cammell, Lairds, at Birkenhead, and launched in 1920.

Since these early efforts, the use of welding in connection with ships has increased enormously. To-day all the large oil tankers are completely welded, and considerable use is made of welding with passenger ships and also with naval vessels. During the war, the opportunity was taken of using labour unskilled in shipbuilding for the construction of small vessels known as 'tids'. These were tugs of seventy feet length and ten feet breadth, and the parts were made away from the sea and conveyed by trailer to the shipyards where they were joined together and the vessels launched. The same policy was used in connection with

various kinds of landing craft. An important application of welding during the war was in the construction of Liberty ships made in America, and supplied in large numbers to make up the shipping losses which were suffered through submarine activities. These ships were all welded, using, in many cases, substantially unskilled labour. Some troubles were experienced with brittle fracture, but the service rendered to the Allied cause by the construction of these ships at very high speed was quite invaluable.

Oil tankers are all welded and the largest afloat to-day is the British-built 47,000 ton *Spyros Niarchos* due for delivery in May this year. This ship is 757 feet long, 97 feet beam and 52 feet deep. The largest all-welded passenger liner—the *Orsova*—belonging to the Orient Fleet, has also recently been built in this country. She has a gross tonnage of 28,870 tons, a displacement of 31,810 tons and is 723 feet long.

[*By courtesy of Shell Photographic Unit*

FIGURE 18. *Automatic welding on a tanker*

The introduction of welding has led to the greatly extended use of prefabrication as a method of ship construction. This facilitates the work very greatly, and enables construction to be done away from the actual slipway. It was used extensively during the war, and very large items, weighing up to forty tons or more, can be made separately, and then fitted into place.

Pressure vessels

In no other industry does welding play a greater part than in the construction of pressure vessels. Whether the vessels are required for steam raising, oil refining, or chemical processing, welding is invariably used where the operating conditions are onerous, that is to say, for high temperatures or high pressures, or where both are combined. In the case of high-pressure boilers, the steam drums are themselves sometimes solid forged; riveting is never used to-day, but perhaps most of the steam drums are made by rolling steel plates and butt welding longitudinally with the provision of special ends which are then welded to the cylindrical portion with circumferential butt welds. Subsidiary equipment, such as superheaters, economizers, all pipework, and condensers, are invariably welded also. The tendency to-day of rising temperatures and rising pressures makes it quite certain that welding is the only possible joining method. So far, boiler drums have been made only from mild steel, but increasing consideration has been given to the possibility of using alloy steel in view of the fact that thicknesses are increasing very considerably. Five inches is not an exceptional thickness to-day.

[*By courtesy of G. A. Harvey & Co. (London), Ltd.*

FIGURE 19. *Welded distillation column for an oil refinery*

Inspection of such welded vessels is of paramount importance, and a great deal of attention has been given to this aspect. Hundred per cent radiography is applied, generally using X-rays, though there is an increasing tendency to make use of isotopes and a minimization of the cost could possibly be effected by the use of ultrasonics as a preliminary inspection method. This is, however, as yet only in the experimental stage.

The oil refining industry requires quite spectacular vessels for use as distillation columns, catalytic crackers, and so on. Some of these vessels are quite exceptional in size; they have been constructed to 19 feet (internal) diameter, and as much as 140 feet long, and the weight may approach 150 tons (Figure 19). The vessels are all erected vertically on the site, and in some cases are erected at some considerable height above ground level. Such vessels naturally present considerable transport problems, and if they have to be transported by road, they usually travel at times when traffic is at a minimum. It is also not unusual to seal the vessels, and transport them by water, using tugs. Another problem which is of considerable importance, is the stress relieving of such vessels, for their dimensions exceed the size of any available stress relieving furnaces. In consequence, the vessels can only be stress relieved in sections.

There is quite a substantial business in stainless steel vessels, especially for the chemical industry, and in vessels in which stainless clad and nickel clad mild steel are used. Sometimes the quality of surface required in such vessels is very high indeed, and considerable effort must be expended in polishing. It is not unusual in the chemical vessel industry to have internal mixers in the vessel, and another common form of construction is a jacketted vessel, or again vessels containing heating coils. All these present quite complicated welding problems, not only in the actual execution, but also in ensuring satisfactory inspection up to the required standards.

The welding of the cylindrical pressure vessels, referred to above, is usually done by automatic welding units, either of the covered electrode, or submerged arc type. In the former case, a current of the order of 1,000 amps is used, and in the latter case, anything from 2,000 amps upwards. The welding heads are generally mounted on a travelling cantilever wall crane or other type of equipment, and for doing the circumferential seams, the work is rotated on rollers. In the case of internal welds, the welding head must be supported on a long arm, which is of sufficient length to reach from one end of the vessel to the other. An alternative arrangement which is sometimes used is to lay rails inside the vessel, and traverse the welding head on these.

The problem of devising the most economical method of joining nozzles to pressure vessels is one which has been given considerable attention by the British Welding Research Association. In the past it has been the practice to fit a collar reinforcement around the pipe or nozzle, but there has been no scientific basis for determining the size of this. It has been discovered in the course of research work that it is much cheaper and more effective to project the nozzle or pipe slightly into the vessel, and to eliminate the use of a patch reinforcement. This projection inwards gives additional strength and its only objection appears to be that if the nozzle is in the bottom of the vessel, it is not possible completely to drain the vessel. As a result of recent researches, the Association is of the opinion that as the thickness of vessels increases, the importance of the reinforcement becomes less. Investigations have not yet been completed, but it is hoped that, as a result of this work, it will be possible considerably to economize in the cost of welded nozzles.

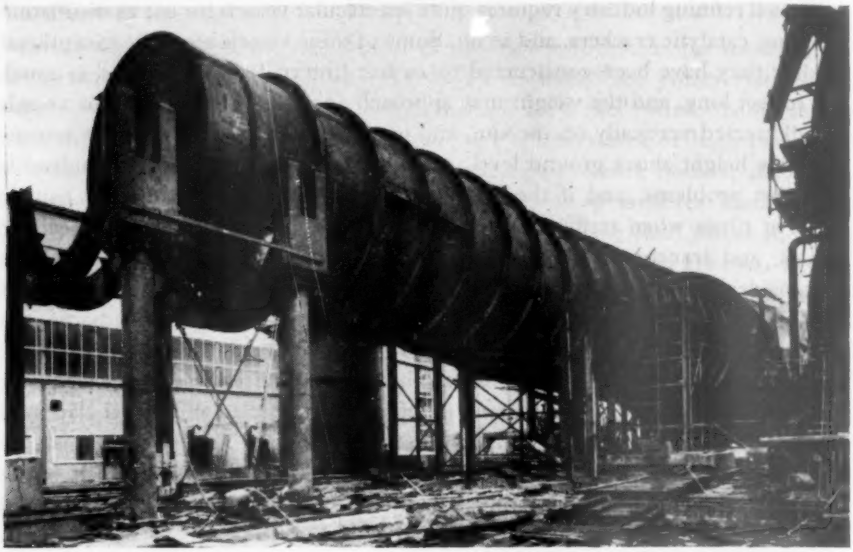


FIGURE 20. *8 ft. by 8 ft. R.A.E. wind tunnel at Bedford*

Wind tunnels

The problems of constructing wind tunnels for the aircraft industry are somewhat analogous to those of pressure vessels. The largest of these has been built for the Royal Aircraft Establishment, and it will be well appreciated that modern requirements of high Mach numbers require very special equipment indeed. Welding plays a prominent part in the construction of wind tunnels.

Such an installation is the 8-foot by 8-foot high-speed wind tunnel of the Royal Aeronautical Establishment, Bedford, which is shown in Figure 20 in the course of erection. It is interesting to note that the plates for this tunnel are from $\frac{13}{16}$ of an inch to $1\frac{3}{8}$ inches thick, and were made from a steel with a controlled Charpy impact value of 35 feet/lbs. at −10°C. The object of this requirement is to minimize the risk of brittle fracture. Nearly 5,000 tons of steel were used in the pressure shell which has a maximum diameter of 47 feet. The tunnel is of the closed circuit type 350 feet long between centres, and eighty feet long between short centres. All the welds in the tunnel were 100 per cent X-rayed to Lloyd's Class I Standard.

Of particular interest from the welding point of view are the flexible guide plates and the diaphragm plates. The former are about eighty feet long and are stiffened with a large number of welded-on T-sections. All the welds were examined by X-rays. The latter are 47 feet in diameter and $2\frac{1}{2}$ inches thick, and through each of them pass no less than 58,000–$1\frac{1}{2}$ inches diameter tubes, These are resistance welded tubes, expanded and welded into the tube plates at $1\frac{3}{4}$ inches triangular spacing. The tubes form part of the cooler which is

required to reduce the temperature of 1,200 lbs. of air per second from 160°C. to 50°C. The air leaving the cooler is to have a uniform velocity and temperature which is to be controlled within $\pm$ 1°C. In the whole structure of the wind tunnel there were 16,000 feet, that is rather more than three miles, of welding and of this less than three per cent was cut out for defects and re-welded. These defects were mainly due to porosity or slag inclusions; cracks in welds or in the parent plates were quite unusual. In order to avoid the possibility of brittle fracture, day and night temperatures during erection were continuously recorded, and welding operations were stopped when the air temperature dropped to 2°C. or below. The radiographic examination of the welded seams, and the interpretation thereof, was a continuous process, since it was obviously desirable that the inspection should follow welding as quickly as possible. In fact, it was usually from fifty to 150 feet of seam behind the welding. Thus the correction of defects was not long delayed.

The magnitude of this enterprise may perhaps be appreciated from the fact that 2¼ million gallons of water were required for the water test, which was carried out at a mean pressure of 67½ lbs./square inch, which is 1½ times the working pressure of the tunnel. With such a large container and such a relatively small pressure, it is obvious that the effect of the head of water must be taken into account. This means, in fact, that when the mean pressure is 67½ lbs., the minimum pressure is 57½ and the maximum pressure at the bottom of the vessel 77½ lbs. In this case, it was possible to make a water test, but it will be appreciated that had this vessel been erected on end, for example, a water pressure test would have been quite impossible, for the head of water would have caused much too high a pressure at the bottom. Moreover, the problem of supporting such a weight of water is quite considerable; even in the horizontal position special supports had to be supplied. Other types of welded vessels than wind tunnels sometimes present similar testing problems from this point of view, and the only solution is to use air, but the risk of so doing is quite considerable.

Oil Refining

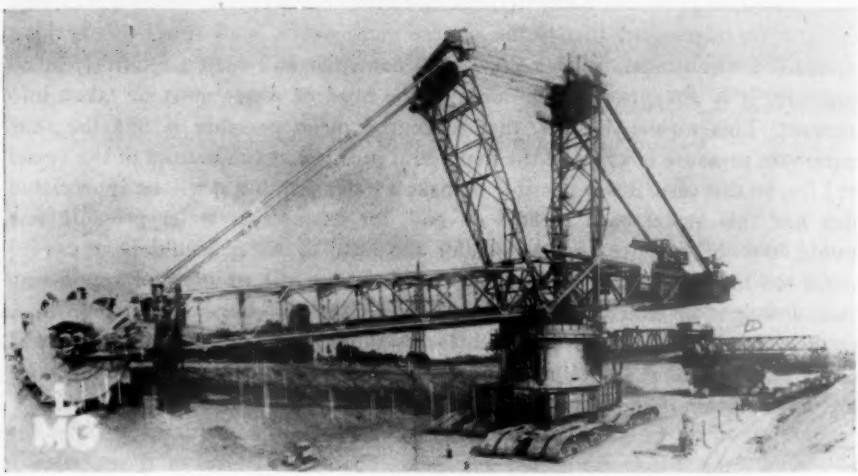
Reference has already been made to the extensive use made by the oil industry of welded pressure vessels. These range from relatively thin vessels which are up to twenty feet in diameter, and 140 feet long, to smaller vessels suitable for very high pressures and temperatures where the corrosion conditions require specially resistant materials which may present welding problems. High pressure welded vessels working at very low temperatures are also used. For oil storage, the industry makes large use of all-welded tanks which may have fixed or floating roofs. These tanks are made from mild steel with special provision where the plate is thick to guard against brittle fracture. Hand welding is generally used, but an automatic process has recently been used in America for the horizontal seams.

Overland pipelines are also welded at the circumferential seams on site, and there are many thousands of miles of such pipeline in existence. There is increasing interest also in such lines for long distance gas distribution in this

country; in the United States overland oil gas distribution is, of course, well known.

Excavators

The drag line excavator used in removing overburden at iron ore quarries has been described. Its size can be matched by an unusual brown coal excavator produced in Germany. This is of the bucket wheel type, and considerable use is made of welding (Figure 21). There are 12 buckets, entirely welded, on the bucket wheel and each bucket has a capacity of 4·6 cubic yards. The wheel is 52 feet in diameter. The overall length of the excavator, including the loading gear, is 220 yards, and it can excavate 10,000 cubic yards of loose material per hour. This corresponds to nearly a quarter of a million tons in three eight-hour shifts.



[By courtesy of Orenstein-Koppelund Lübecker Maschinenbau A.G.

FIGURE 21. *Bucket wheel excavator for brown coal*

With such a duty cycle, the welding must be of the highest quality to stand the dynamic loading conditions on the buckets, and there is no doubt a substantial repair problem in maintaining by welding the hard surfaces on the bucket teeth.

Atomic Energy

During the course of this lecture, we have shown the increasing importance which welding is playing in industry to-day. In transport, in pressure vessels, in the oil refining industry, in general engineering and in many other aspects, but none exceeds in importance the most outstanding development of the

twentieth century, namely, the application of atomic power. Developments in this field would have been virtually impossible without the use of welding. The requirements are so stringent, quite different from anything which has been required before, that they could not possibly have been met unless welding had developed to its present high pitch of excellence. Naturally, much of the equipment which is used, and details of methods of construction, are confidential, but a good deal of general information is available, and reference might first be made to the chemical engineering plant which is used by the Atomic Energy Authority. This comprises vessels of all kinds and descriptions, mainly in mild steel, light alloy, and stainless steel. With stainless steel, a choice was made in the early days of a type of steel which presented particular welding difficulties. These, however, have been overcome, as have other welding problems in matters relating to atomic energy.

Amongst the various materials used in the construction of the Atomic Energy Authority factories, are many miles of large diameter aluminium pipe, which in certain cases have been joined by welding to a high degree of vacuum tightness. Resistance to leakage is of the very highest importance, and exceptional care is, therefore, taken over leak testing, but an industry which has acquired the art of welding vessels up to very high pressures which are completely reliable, did not find very great difficulty in making other vessels capable of standing atmospheric pressure indefinitely. It is generally known that much of the equipment which is used by the Atomic Energy Authority can virtually never be inspected. It is, therefore, essential that the welding should be of the highest quality, and very great care is taken with non-destructive testing.

Coming now to specific applications, reference may be made to the Calder Hall atomic power station. Basically, this consists of two very large all-welded reactor vessels contained in concrete buildings some 120 feet high. Outside each building are four heat exchangers which are the boilers of the power station. Through these steam generators, passes the high temperature high pressure carbon-dioxide from the atomic reactor. The heat of the carbon-dioxide is passed through the heat exchanger to the water and steam for the normal low pressure steam turbines. These steam generators were made from Coltuf steel and are 17 feet 6 inches in diameter by eighty feet high and 1·3 inches thick, the ends being $1\frac{3}{4}$ inches thick. They were made up in a series of rings at the contractor's works; these rings were then shipped in halves to the site, and joined together and joined to one another at the site of Calder Hall. As is usual with pressure vessels, stress relieving was necessary, and this was carried out on site by induction heating—an exceptional job done in an unusual way. Each of the reactor's four steam generators contains tubes with 10 million studs welded on them, the purpose of which is to increase the area of the tubes exposed to the hot carbon-dioxide gas. Flash-butt welding is used for attaching the studs which are eliptical in section, and measure about $\frac{1}{2}$ inch by $\frac{1}{8}$ inch. They are flash welded at the rate of 1,000 to 1,500 per hour per man per machine, but even at this high rate, many months and many flash welding machines are required for the forty million studs required for each reactor.

The empty shell of each heat exchanger for each reactor at Calder Hall weighed 180 tons, and after tubing each weighed 550 tons. Exceptional cleanliness requirements inside the vessels had to be met—studded tubes, men and tools, all had to enter through a temporary intermediate chamber used as a dust trap and for controlling the humidity of the air in the heat exchanger.

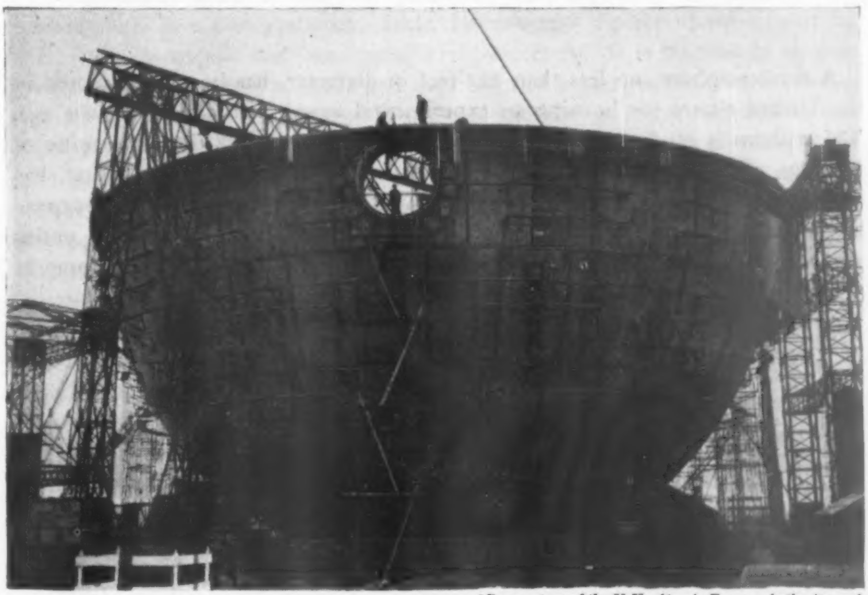
The reactor vessel is much iarger than the heat exchangers and is made up entirely from shaped plates. It is about 35 feet in diameter and seventy feet

[*By courtesy of Whessoe Ltd.*

FIGURE 22. *Calder Hall atomic power station—lowering the first section of the welded reactor vessel into position*

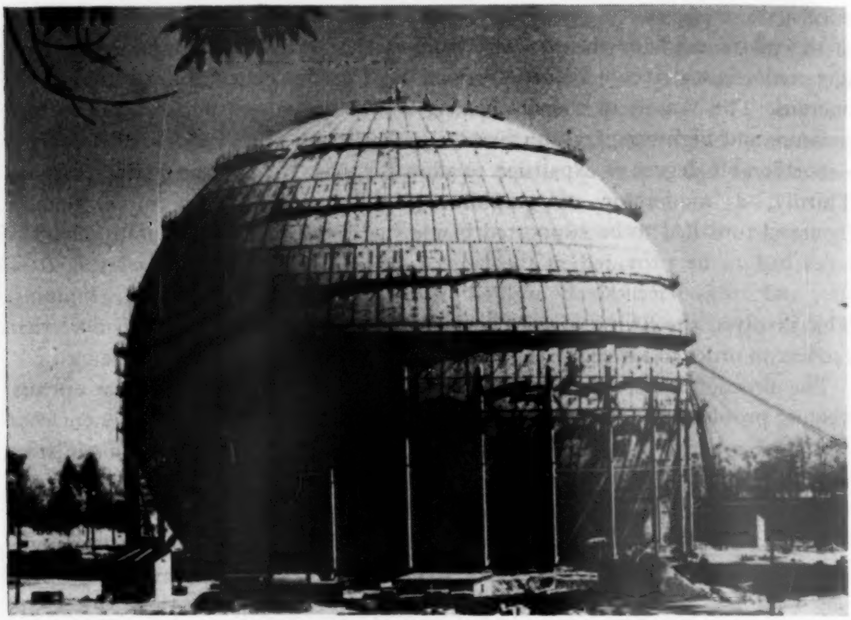
high. All the welds were completely X-rayed to Lloyd's Class I Standard, and once again stress relieving on site was used. It is interesting that every square foot of the plates used for the pressure shell of the reactor was examined with an ultrasonic flaw detector before fabrication. The design conditions were quite onerous. The vessel, in the first place, would contain carbon-dioxide at high pressure and high temperature. Secondly, the design of the vessel had to permit a considerable degree of expansion to allow for these temperatures and pressures. Thirdly, a moderator of graphite weighing considerably more than a thousand tons had to be supported inside the vessel. Fourthly, a multiplicity of holes had to be provided in the reactor shell. The vessel was constructed on site, and rings successively welded in position inside the concrete building. This involved the lifting of very considerable weights to a height of more than 120 feet in order to lower the successive pieces into the building (Figure 22).

The Breeder Reactor at Dounreay in Caithness also presents some unusual welding problems for, as a protective measure, the reactor is completely enclosed in a steel sphere, 135 feet in diameter (Figure 23). The sphere is made from shaped plates of steel specially treated to minimise the risk of brittle fracture. The plates are up to 12 feet 6 inches wide by 25 feet long. The preparation for welding was the normal double v butt with a root face. Low hydrogen electrodes were used throughout, all welded joints being examined by X-rays. The total weight of steel involved is about 1,500 tons, and there are about two miles of welded seam.



[By courtesy of the U.K. Atomic Energy Authority and The Motherwell Bridge and Engineering Co., Ltd.

FIGURE 23. *Dounreay atomic power station— the all-welded protective sphere in course of erection*



[*By courtesy of* Welding Engineer

FIGURE 24. *Protective sphere for housing experimental atomic submarine*

A similar sphere, no less than 225 feet in diameter, has been constructed in the United States for housing an experimental atomic submarine (Figure 24). This sphere is made from one-inch plates, and has no less than five miles of welding, all of which again has been inspected. This sphere, in addition, has a quarter of a million $2\frac{1}{2}$-inch long studs welded on the outside for the purpose of holding a layer of fibre glass thermal insulation to cover the entire 160,000 square feet or four acres of surface area. This sphere has a volume of nearly 6 million cubic feet.

LECTURE III

Monday, 30th April, 1956

RESISTANCE WELDING

Resistance welding is the process of joining metallic parts together by the heat generated mainly by the resistance created at their points of contact when a current is passed between them. British-born Professor Elihu Thomson is rightly regarded as the inventor and founder of the process which is so widely used to-day and without which modern mass production methods of construction would be almost impossible. There is some evidence that Professor Thomson was not quite the first to use resistance heating for welding. For example, in 1857 Joule called attention to the possibility of joining metals in this way though Lord Kelvin (then Professor William Thomson, but unrelated to Professor Elihu Thomson) first made the experiment. Joule reports having joined together in this way a bundle of iron wires and also to have joined steel to brass and platinum to iron.

Thomson's patents were taken out in 1886, though they were based on ideas which came to him in 1877. He was lecturing at the Franklin Institute in Philadelphia, using an induction coil in the reverse direction. The heavy currents, which passed through what is normally called the primary winding, caused a fusion together of the ends of the wire. This experiment remained dormant in Professor Thomson's mind for several years until the need for an effective method of joining together ends of copper wires presented itself. Apparently it was difficult to get wire of any considerable length in one piece, and welding together several joints in a coil was unavoidable. He designed a piece of equipment for doing this electrically and was immediately successful. It is interesting to note that between his first experiment and the filing of his patents, resistance welding appears to have been commenced at the cable making works of Siemens in this country. Here the steel armour wires were joined by a resistance-welded scarf joint which appears to have been entirely satisfactory, tests fracturing as often outside the weld as in the weld. It is curious that this practice appears not to have invalidated Thomson's patent.

The history of resistance welding in its early years is quite well documented. Several papers presented to the leading engineering societies in this country in the 1880s and the 1890s give a considerable amount of information. In one of these to the West of Scotland Iron and Steel Institute, the author, Mr. Duff, describes a butt welding machine which he saw in use at the works of Messrs. Clarke, Chapman & Co. This was in 1893, when the machine had been installed for several years. It was one of the earliest productions of the Thomson Electric Welding Company and is, in fact, still in use to-day—66 years after it was installed—doing the same job as that for which it was originally provided.

The development of resistance welding early in the present century was distinctly slow, and the retardation was undoubtedly due to the fact that in the early days no welding apparatus was disposed of outright. Each welding unit was built for a specific operation and was installed only on a royalty basis. On ordering the equipment, the purchaser had to deposit a certain sum for the

right to use the process and for the possession of the machine. If the machine was in satisfactory condition at the end of three or four months, the economy effected by the use of the method was calculated by comparison with the cost of ordinary joining methods. The purchaser then paid to the vendor a sum calculated on this basis—so much per completed weld, the number of welds made being registered on a counting device mounted on the machine. The sum paid amounted to 25 to 33 per cent of the economy effected. This arrangement continued for many years, and was considered fair and equitable to both parties, because the new method of welding was so far superior to the old methods of joining that it proved profitable to all concerned. As a result of this commercial arrangement, the business remained in the hands of one company until 1916 when, after many law suits, five others were licensed to produce welding machines.

The patents taken out originally by Thomson were drafted in wide terms, and although at the time he clearly envisaged only butt welding, it was finally decided by the United States Supreme Court in 1924 that they also covered spot welding. The commercial arrangements which were made by Thomson's company, and the excessive patent litigation on the subject of welding, undoubtedly slowed up its development both in America and in this country.

Butt welding, which was so popular in the early days, is now of only limited application. It depends on the continuous pressing together of two parts to be joined whilst a current is passing between them. Fusion eventually takes place at the contacting surfaces at which there is an increase of size due to the softening of the surrounding metal. The primary use of the process to-day is for joining wires in wire-drawing mills.

For the majority of joining applications, butt welding has been replaced by flash-butt welding, in which the parts are first brought together under light contact, when flashing and melting occur at the surfaces. The pressure is then increased and the two parts are forced rapidly together with the extrusion of oxide and metal which form a flash or fin which freezes around the joint. This is an effective cleansing process which means that the two parts which eventually come into contact consist of pure metal. Figure 25 shows typical flash-butt welding applications. These include fork

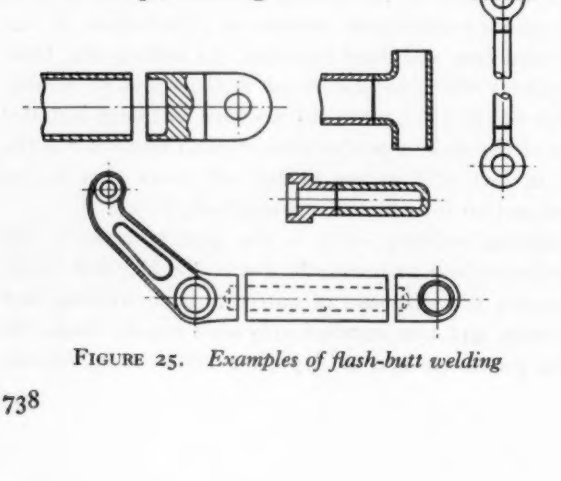
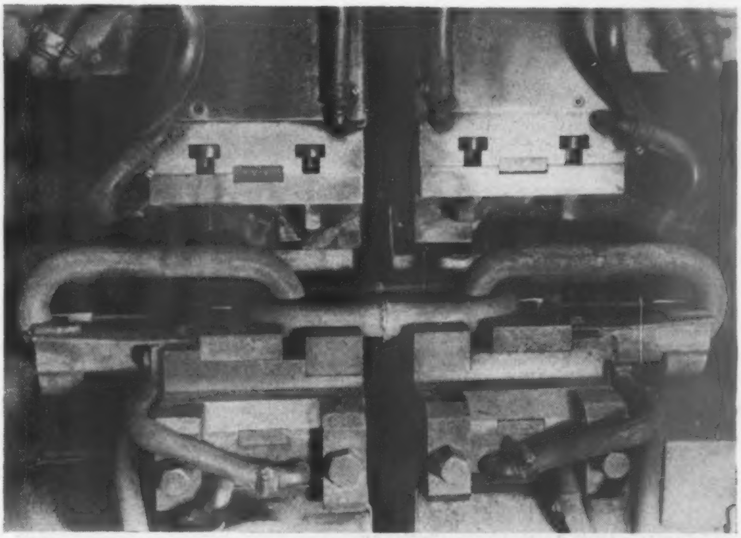


FIGURE 25. *Examples of flash-butt welding*



[By courtesy of A.I. Electric Welding Machines, Ltd.

FIGURE 26. *Flash welding of three-link couplings—note the fin of metal formed*

ends for tie rods, tubes, mitre joints of window frames, and there are many other applications. It is usual to remove the flash by grinding subsequently to welding. Flash welding is frequently used for the construction of chains wherein the wire is formed into a loop and a single flash-butt weld completes the link. In the case of larger chains such as three-link couplings for railway coaches, the links are formed into two U-shapes and two flash welds are made at the same time. This is shown in Figure 26.

Spot Welding

Spot welding is the commonest form of resistance welding. It is most clearly described in the patent filed by Harmatta in 1903, and though this was finally declared invalid, it was evidently the introduction of the process. Harmatta says:

> The invention affords a cheap and practical substitute for riveting and is particularly useful in fastening plates and sheets of metal to one another. . . . In general terms the invention may be stated to consist in fastening the pieces together in an electric weld at one or more distinct or well-defined spots . . . by the application of pressure and heating current.

A pair of copper or copper alloy electrodes, which are water cooled, are generally used. These apply the pressure to the work where welding is required, and serve to carry the current which is of the order of thousands of amperes flowing for a period up to several seconds. The resulting spot weld which is formed is shown in Figure 27. Conditions vary considerably, but the weld should occupy between twenty per cent and eighty per cent of the thickness of the two sheets—

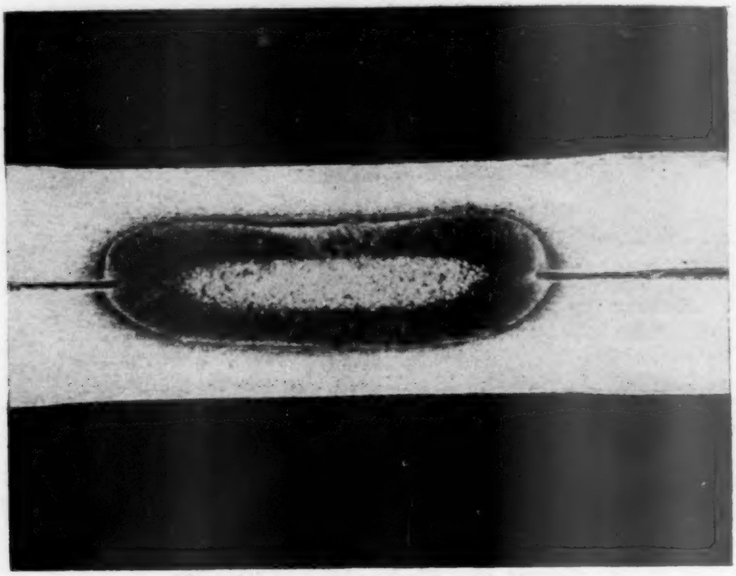


FIGURE 27. *A typical spot weld*

the thinner the sheets the smaller the figure—and should not contain cracks or blow-holes, neither should there be excessive indentation on the outside of the sheets. The method is particularly appropriate for mild steel, but also has wide application with stainless steel, alloy steel, and aluminium. In the early days, spot welding was done with small pedal-operated machines in which a mechanical contrivance arranged that the pressure was brought on before the current and was switched off before the electrodes were separated. The pedal-operated machine is now less common than it used to be, and all large machines are operated pneumatically. Moreover, there is much more complicated timing gear than used to be employed. This equipment ensures that the current flows for a very precise period of time which may be measured down to an accuracy of half a cycle. Resistance welding transformers generally operate from the normal power supply on the primary side, and have a single turn secondary. The secondary voltage is generally somewhere between two and ten volts, and the current may be many thousands of amperes. The impedance of the secondary circuit is made up of the resistance of the circuit, which is considerably influenced by the condition of the mechanical joints, and by the reactance which is determined by the configuration of the machine. Thus, spot welders which require a large gap between the arms, or which must have very long arms in order that the spot weld may be made in the middle of a sheet, have a high reactance, whereas projection welding machines which have short, stiff arms have a small reactance. Whilst the general procedure is to make one weld at a time with simple machines, series welding in which two welds are made together is not uncommon,

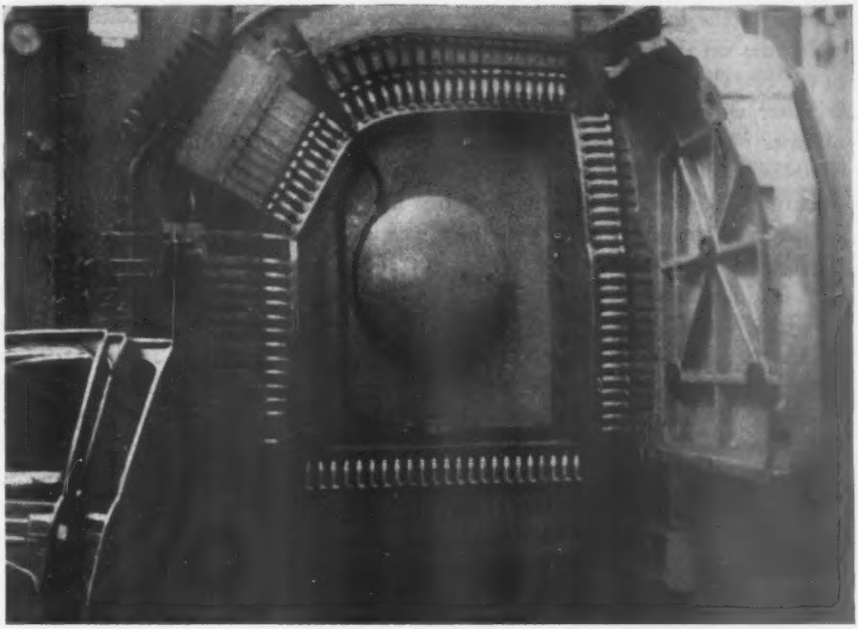


FIGURE 28. *Multi-electrode spot welding machine*

and in modern plant this process has been multiplied many times so that hundreds of spot welds can be made substantially together.

The development of spot welding is linked closely with the development of the motor car. It was first used for parts of cars in 1912, but within very few years became an absolute necessity, and the construction of modern cars would virtually be impossible without spot welding. Two methods are used—gun welders, that is portable spot welding machines, and secondly, the use of the press type welding machines in which large numbers of small spot welders operate at the same time. Such machines join together pressings for doors or chassis of motor cars. They are very elaborate and expensive machines, and can only be justified where a large number of similar products are made. In such machines, series welding is generally used, and the electrodes are hydraulically operated with spring return. Various arrangements are necessary to limit the power demand on the mains. This is done by ensuring that only a limited number of electrodes fire at the same time. Synchronization between the hydraulic and current control is necessary to ensure that the current is switched on after the electrodes come into contact, and off before they part. A multi-electrode spot welder for motor car doors is shown in Figure 28. This machine makes ninety welds in twenty seconds.

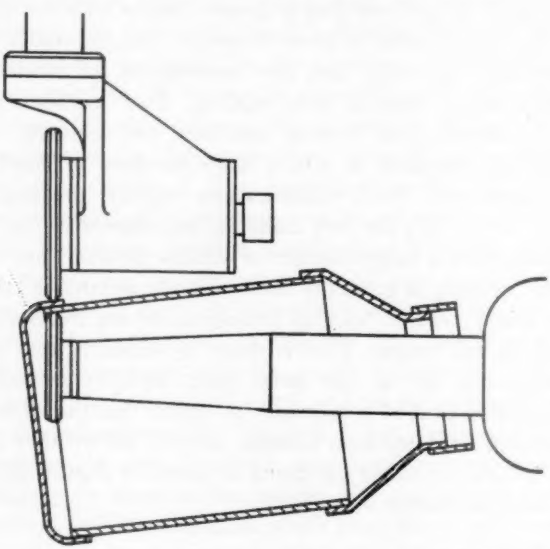
Projection Welding

A development of spot welding is known as projection welding. In this method,

instead of the location of current flow being determined by the position of the electrodes on the work, it is pre-determined by the position of dimples in one of the two sheets which are to be welded together. The sheets are then squeezed together with flat electrodes and a series of spot welds, corresponding to the number of dimples, is formed at the same time. The proper shaping of the dimples is a matter of some importance, and has been the subject of extensive research. The obvious advantage of this method is that a number of spots can be made at the same time, and their location precisely determined. Naturally much heavier pressures and higher currents are required for such machines than for machines making one spot at a time. There are variations of the process in which shaped projections, rather than dimples, are used when solid parts such as studs have to be attached to sheet. In such cases, an annular ring or ridge may be used as a contact point, instead of a conical pip. The development of suitably shaped heads for welding bolts to sheets was a subject of investigation by the British Welding Research Association and, as a result, it was possible to reduce the thickness of the head and its diameter and at the same time to determine the most satisfactory radius. This, it was finally decided, should be twice the diameter of the bolt, and the diameter of the head need be no more than $\frac{1}{8}$-inch greater than the diameter of the bolt.

Seam Welding

Seam welding is a popular and useful method of joining parts together. By this method, continuous pressure-tight joints can be made, and it has wide application in the light container industry. Both circumferential and longitudinal welds can be made with equal facility. The method uses generally two wheel



[*By courtesy of Sciaky Electric Welding Machines Ltd.*

FIGURE 29. *Seam welding of a milk churn*

electrodes—one of which is driven. Pressure is applied to the joint through the wheel rims through which also the current passes. The flow of current is intermittent, being controlled generally to-day by an electronic timer, the duration of flow of current being controlled and also the interval between the times of current flow. In this way, virtually a series of spot welds is obtained which may be separated, or may overlap—an essential requirement where pressure tightness is necessary. Figure 29 shows diagrammatically the seam welding of a milk churn.

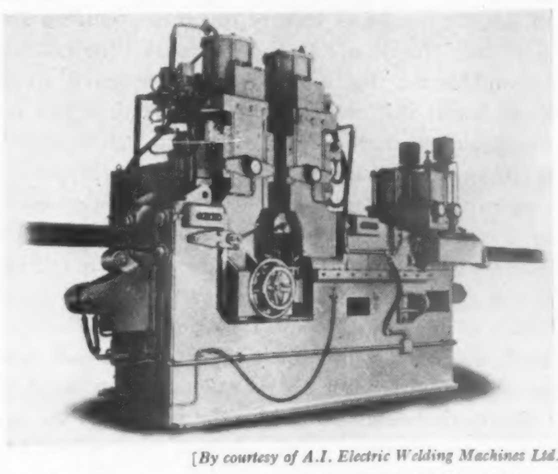
Seam welders are generally fixed machines, but occasionally portable machines have been made.

Special Machines and Applications

Flash-butt welding had a great vogue in the motor car industry for some years, being used to join together the edges of large pressed parts. This involved very large and heavy machines with elaborate clamping devices, but the process was eventually displaced because of the difficulty of concealing the joint.

The same method is used for joining together steel strip in the rolling mill process where joints up to perhaps six feet wide in quite thin sheet can be satisfactorily made so that the rolling is continuous.

Flash-butt welding of rails is also an important application of the process. This was first done in 1924, and after a slow start has now become a routine job which is fast approaching standard practice throughout the world. British Railways, who have been welding rails for some years, are constructing a number of rail welding depots, details of which have been given in the technical press. Figure 30 shows a rail welding machine. It is usual in this country to weld together lengths up to 300 feet, but there are at least two continuous lengths of rail of over a mile. Whilst flash welding is done in depots, site welding is done by the 'Thermit' process. There are in various parts of the world continuous lengths of rail of many miles, and there appears to be no difficulty arising from temperature changes. Welded rails show many advantages with substantial savings over the previous system of short lengths with fish-plated joints. There is reduced track maintenance with reduction of shock loading and consequent tyre wear on rolling stock. There is also increased comfort to the traveller. Special machines have been devised



[*By courtesy of A.I. Electric Welding Machines Ltd.*

FIGURE 30. *Flash-butt welding machine for rails*

for this process in which heat treatment of the weld takes place subsequently to the welding operation. Good alignment of the rails is, of course, necessary before the welding operation, and provision is made in the equipment for ensuring this. After the weld is made, the flash must be removed, and this is generally done whilst the rail is still hot, by a pneumatic chisel. A 110-lb. rail is welded in a time of about two minutes, with an energy consumption of about two units per weld. The normalizing of the rails subsequently to welding is done by heating to 850° C. for a distance of four inches on either side of the rail. This can be done by furnaces, but in some cases provision is made for doing it by means of resistance heating. The surface of the rail must be ground flush after the chipping operation, and the weld must be capable of standing a Tup test consisting of a one-ton weight dropped from a height of twenty feet, the rail being supported at 3 feet 6 inch centres. It is interesting to note that there is no difficulty in transporting, on a string of trucks, lengths of rail up to 300 feet; the rails bend quite satisfactorily around the curves.

Operation Pluto

Operation Pluto consisted in laying two types of pipeline under the English Channel, namely the HAIS cable, which consisted of an electric submarine cable, without cores and insulation, through which petrol could be pumped, and the HAMEL pipe line consisting of three-inch nominal bore steel tubes electrically flash-welded together into the full length required for laying, this length being coiled round floating drums from which it was unwound again on the bed of the Channel.

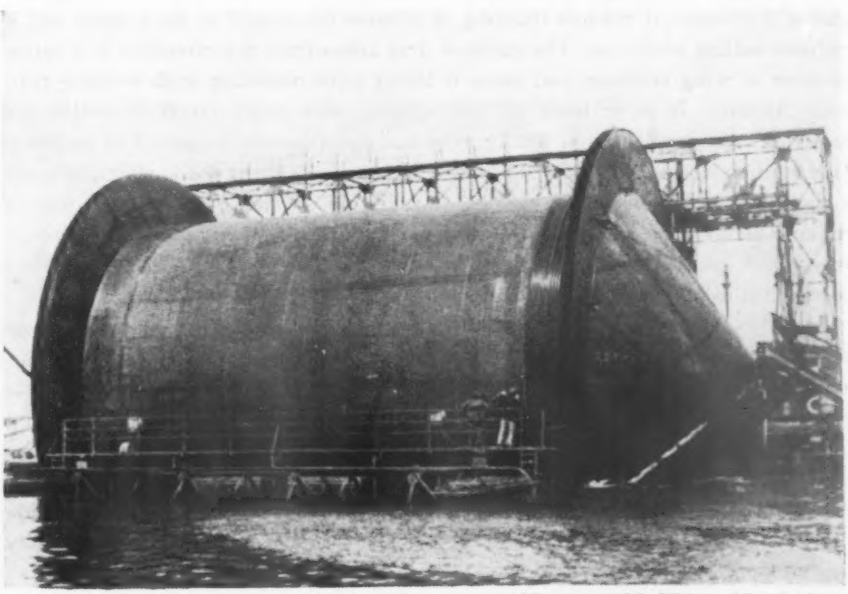
When proposals were made for the Hamel pipe early in 1942, it was to consist of a continuous steel tube three inches in diameter, wound on a forty-foot drum which could be towed across the channel, the pipe being unwound on the way. The tube would have to be eighty miles long and the longest solid drawn three-inch tube which could be made was forty feet. The only feasible method of joining forty-foot lengths of tubes of such a small diameter was by electric flash-butt welding. At the National Physical Laboratory it was established beyond doubt that a steel tube of required specification could be flash-butt welded and the weld subjected to bend, repeat bend, and tensile tests giving equivalent properties to that of the parent metal. In order to maintain the quality and consistency of the weld joint, only fully automatic machines could be employed and 16 flash-butt welding machines, each with a transformer capacity of 180 kVA and operated by oil pressure, were installed at the special site at Tilbury. The forty-foot lengths of tube were fed into the factory from a railway siding at the rear and by conveyors to each welding machine. By this means it was possible to have all 16 welding machines in operation simultaneously. Each weld in the three-inch diameter pipe took about 15 seconds and a welding production programme of 12 miles of pipes per day was maintained.

From the welding machine the sections of the pipe line, now each 4,000 feet long, were conveyed to the winding ramp where 400 miles of welded pipe could be stored; but before that could be done the external and internal flash created

by the forging action during welding had to be removed. Whilst the external extrusion presented little difficulty, the removal of the internal flash from the bore of the tube forty feet from the end was a more serious problem. It was, however, accomplished successfully by a cutting tool, incorporating a steel wire brush and reverse blowing nozzles inserted into the tube prior to welding. The driving spindle was 45 feet long, passing through the forty-foot length of tube being welded, and had a rotating action when drawn back for a distance of three feet, which was sufficient to clean the weld extrusion.

The welded tubes were ultimately wound on a large steel drum resembling a huge cotton reel with conical ends, ninety feet long and fifty feet in diameter over the flanges. The part on which the winding was to take place was sixty feet long and forty feet in diameter, allowing a total radial thickness of some five feet of wound pipe. Fully wound, such a drum would hold about 19 layers of three-inch pipe, each layer consisting of about 180 turns, the actual total length being about 92 land miles or 3,416 turns (Figure 31). Various trial lays were carried out with these drums and they were found to operate quite successfully even in rough seas, although very powerful tugs were required to tow them.

A total of 970 miles of pipe was made, incorporating some 198,000 flash-butt welds and the weight of pipe welded within the period was 17,120 tons. Pumping stations on the English shore from which the pipeline ran into the sea had also



[By courtesy of the Ministry of Supply, Armament Research and Development Establishment

FIGURE 31. *Flash-butt welded pipeline 'Pluto' being coiled on to laying drum*

to be prepared. These stations were at Ventnor and Dungeness. Their preparation involved a great deal of secret work and careful camouflage, the pumps being installed in bungalows, ice-cream parlours, fair grounds, and so forth. This part of the operation was carried out so well that no hint of the position of these pumping stations appears to have been given to the enemy. Lines were first laid from Ventnor to Cherbourg but, as it became possible much earlier than was expected to operate the scheme further east, the main lines (six Hamels) were laid between Dungeness and Boulogne.

No exact data are available as to the delivery quantities from the various lines but it is known that the quantity delivered to Cherbourg was about forty g.p.m. per line with a pressure of abut 1,250 lbs/sq. in. and about eighty g.p.m. at the same pressure for the shorter lines to Boulogne. Altogether, when the scheme was working fully, about one million gallons of petrol a day were pumped across the Channel.

Aircraft

There is considerable divergence of opinion about the best method of making joints in aircraft. The first and still the commonest method is by means of the hollow rivet. The latest method is by the use of adhesives. For many years, spot welding has been employed, and much research has been done on the proper preparation of the aluminium alloy sheets. Very great use is made of spot welding in a limited range of British aircraft, but apparently a considerably wider use in the United States. The advantages of welding as compared with riveting are that it is cheaper, it reduces the drag, it reduces the weight of the aircraft and it reduces sealing problems. The reduced drag arises from the retention of a better contour of wing sections, and there is better joint matching with welding than with riveting. It is perhaps seldom realized how many rivets or welds are required in an airplane, but the figure is not uncommonly measured in millions. One million $\frac{3}{16}$-inch diameter aluminium rivets weigh 173 lbs.—which is quite a significant addition to the weight of an aircraft. Welding, moreover, permits reduced overlap on joints, and a case has been cited with a transport aircraft where 460 lbs. of weight were saved due to a reduction in the amount of sealing compound used.

In the case of one American aircraft, it was proposed to use integrally stiffened wings made by hot pressing. Unfortunately, the necessary presses were not available at the time, and it was essential to change over to spot welding. This was done without modifying the gauge of the material and without increasing the weight of the aircraft. One thousand of these aeroplanes have been made, and it is reported that there is no single case of trouble with the spot welding. Other examples of welding on aircraft are the use of spot and seam welding for outside fuel tanks, and flash-butt welding of under-carriage parts which are generally made from tubular alloy steel.

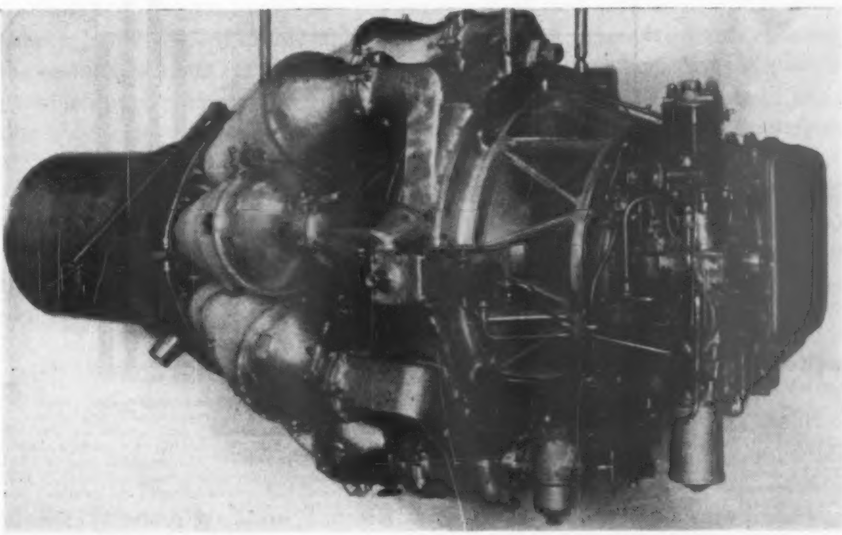
An important application of spot welding to aircraft is the Handley-Page 'Herald', a recently introduced aeroplane designed for operation on short-to-medium range branch lines and able to carry 44 passengers or freight. This

aeroplane contains over 100,000 spot welds, many of which are in the primary structure which is something of an innovation for British aircraft.

Jet Engines

The use of resistance welding in the construction of modern jet engines is an important modern development which is vital to the efficient production of this type of machine. Flame tubes, exhaust units and jet pipes make use of a number of different types of heat resisting alloys, each of which presents its own welding problems. The situation, moreover, is sometimes complicated by the need to join different types of materials or different thicknesses of materials together. An essential requirement in this field is an exceptional degree of accuracy with very thin sheet material. This has led to high precision work of a quality which is unexcelled in any other branch of industry.

In the resistance welding processes, spot, roll spot, and seam welding are the principal methods used, though there is some application of flash-butt welding. In the case of the Derwent engine, which is illustrated in Figure 32, the exhaust unit consisting of an outer truncated cone, made from stainless steel sheet, is machine welded to flanges on each end, and this cone is joined to an inner cone by cross-tubes made from Nimonic 75 spot welded to austenitic steel. Jet pipes are commonly made from a number of cylinders which are wrapped and seam welded longitudinally and joined together with circumferential seam welding. The flanges which are roller spot welded to the jet pipe, are made by flash welding the two ends of a flat hoop together before forming the shape by rolling.



[By courtesy of Joseph Lucas (Gas Turbine Equipment) Ltd.

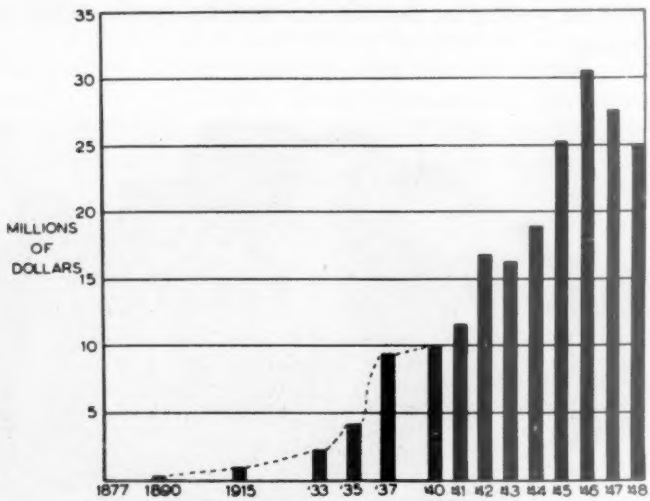
FIGURE 32. *Rolls Royce 'Derwent V' jet engine*

Economics of Resistance Welding

Cost comparisons for resistance welding *versus* arc welding, or for welding against other methods of construction, are not often available, but Stanley in his book on resistance welding says that careful comparisons were made during the war between the cost of spot welding and riveting light alloys in the aircraft industry. He states that skin panels measuring 24 inches by 60 inches were stiffened by five stringers. He quotes flush riveting for this job as taking nearly three times as long as spot welding. Similar more recent information has been given relating to the Matador guided missile. This was automatically riveted for four months, and the method was then changed to spot welding. For riveting, 7·9 man-hours were required for assembly, whereas for spot welding the figure was only 1·7. Stanley compares the cost of arc welding armour plate with resistance welding using automatic spot welding machines. He deduces that 38 machines manned by semi-skilled men could do the same job as 200 highly skilled arc welders. The saving was estimated to be such that even if the spot welding machines cost as much as 50,000 dollars each their cost would have been saved in the first year.

Growth of the Industry

A chart (Figure 33) based on American statistics shows how the resistance welding industry—as expressed in terms of sales of resistance welding machines



[By courtesy of W. A. Stanley and McGraw Hill & Co.

FIGURE 33. *The growth of the resistance welding industry in the United States*

—has grown since it was first introduced. Recent figures have probably exceeded the wartime peak. There is no reason to think that similar developments have not taken place in this country.

CONCLUSION

And so we come to the end of the welding story. I have shown the brighter side of the picture, but the very fact that there exists a research association devoted to welding is evidence enough that we are far from solving the last welding problem. In the first lecture, an account was given of the tools of the trade and the methods of using them—the good old standby, the hand-operated metal arc electrode, which for all its defects probably still accounts for ninety per cent of the electric welding which is done; its big brother the automatic metal arc electrode in two forms, the coiled coated wire, and the bare wire using a powder flux; the tungsten arc with shielding gas, so suitable for light alloys and special steels; and finally, the gas shielded metal arc—that modern high speed process which lays metal down so quickly that its economic advantages can be lost if there is not equal acceleration in the ancillary processes.

The second lecture describes the applications of welding—applications which cover all phases of engineering and much of our every-day life. From bicycles to boilers, from horse-shoes to highway bridges, from tool tips to tankers, not forgetting heat exchangers, motor cars, giant excavators, dock gates, rockets, steel frame buildings, aircraft, and nuclear power plant—in all these welding plays a large and vital part.

Research is necessary to ensure that the best use is made of existing methods, to find the limitations and applications of other methods and to solve some of the elusive problems which inevitably arise when an attempt is made to join cold wrought metal by hot cast metal.

In the broad field of increased productivity, welding is playing a great part. There is considerable scope, however, for improving productivity *in* welding, that is in reducing the man-hours per ton of welded steelwork, and some research effort is being devoted to this important field too—not so much towards choosing the best method, but rather towards ensuring, with any method, that the greatest possible output per man for the required quality is obtained—bearing in mind that the welder himself is only one of quite a number of men who contribute to this figure.

There is no limit to technical developments, and we should do well to adopt the motto that 'there must be a better way'—if only we can find it, but it may well be that the greatest advance in the next few years will be made by improving the application of the tools which we already have at our disposal.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge help received in the preparation of these lectures from: Mr. W. Andrews; Mr. R. G. Burt; Mr. H. E. Dixon; Dr. N. Gross; Mr. P. T. Houldcroft; and Mr. P. L. J. Leder.

Slides and illustrations have also been kindly lent by the following:

Admiralty, Engineer-in-Chief's Department; A. I. Electric Welding Machines Ltd.; W. S. Atkins and Partners; Babcock and Wilcox Ltd.; The British Aluminium Co., Ltd.; The British Oxygen Co., Ltd.; Professor W. Fisher Cassie; Costain-John Brown Ltd.; The English Electric Co., Ltd.; Guest, Keen and Nettlefolds Ltd.; G. A. Harvey and Company (London) Ltd.; Havelock Engineering Company Ltd.; Her Majesty's Stationery Office; Joseph Lucas (Gas Turbine Equipment) Ltd.; Midvale-Heppenstall Co., Philadelphia; Ministry of Supply, Armament Research and Development Establishment; The United Kingdom Atomic Energy Authority and The Motherwell Bridge and Engineering Co., Ltd.; Murex Welding Processes Ltd.; Orenstein-Koppel und Lübecker Maschinenbau; Philips Electrical Ltd.; Quasi-Arc Ltd.; Sciaky Electric Welding Machines Ltd.; *Scope* and Morfax Ltd.; Shell Photographic Unit; Siemens, Schuckertwerke Aktiengesellschaft, Berlin; South Durham Steel & Iron Co., Ltd.; W. A. Stanley & McGraw Hill & Co.; Stewarts and Lloyds Ltd.; John Summers & Sons Ltd.; Thompson Brothers (Bilston) Ltd.; Tubewrights Ltd.; Vickers-Armstrongs (Shipbuilders) Ltd.; *Welding & Metal Fabrication*; *Welding Engineer* Chicago; Whessoe Limited.

GENERAL NOTES

COVENTRY CATHEDRAL WINDOWS EXHIBITION

An exhibition that is worth seeing at the moment is that of the stained glass for the new Coventry Cathedral, now on show at the Victoria and Albert Museum, where it will remain until 30th September. It forms part of the large commission given to the Royal College of Art who selected Mr. Lawrence Lee, Mr. Keith New and Mr. Geoffrey Clark to design and carry out the work.

Six of the ten nave windows which will eventually be erected in the Cathedral are on view. Such an enormous display of glass—each window is seventy feet high—is a little overwhelming, but this is because the floor space available does not afford sufficient room to arrange the windows farther apart, as they would be in the Cathedral.

Each window conforms to a colour scheme set by the Architect, Mr. Basil Spence, A.R.A., and, to quote Mr. Lawrence Lee, the windows 'are semi-abstract in design with themes broadly based on the progress of Christian man through this life to the world to come'. This method of design is well suited to the architecture where the windows are so arranged that they face diagonally towards the altar, which is the one place from where they may all be seen as a complete scheme. The altar is not in the customary position, in the east, but in the north, so that all the nave windows will receive strong southern light.

This good light enables the designers to employ an orthodox technique of painting, using varying textures of patterns and half tones to control their medium. Taking into account the sweeping lines of composition running through the mullions and transom bars, the arrangement of colour and the way that paint has been used, parts are curiously reminiscent in effect of the later periods of mediæval stained glass. At the moment the glass is lit by artificial light, which cannot convey the brilliance it will have when set in the fabric of the Cathedral. Some of the colour passages are distorted, for instance in some cases whites appear yellow, and purples, in the red window, do not show to advantage.

An unusual feature of these windows is that they are only two feet from the floor, whereas in most of the cathedrals the glass is usually well up above eye level and set against the sky. It is certain that some of the richness of colour must be lost in the bases of the windows when viewed against the ground.

What must be one of the most difficult parts of this commission is to maintain a balance with the tone values of the colour schemes in each window, particularly when three designers are employed, each with their own respective windows. The danger is that if some of the windows are too light they could make the others appear too heavy and *vice versa*. However, there is enough glass displayed to enable one to see that a happy relationship has been preserved between one window and another, and the artists are to be congratulated on what must be an outstanding achievement in the medium of stained glass.

CARL EDWARDS

MEDIÆVAL PAINTINGS EXHIBITION

An exhibition of fourteenth- and fifteenth-century paintings, eight panels from the church of St. Michael at Plea in Norwich, is also at present on view at the Victoria and Albert Museum, where it will remain until 28th October. The paintings were brought to London for restoration, and this work was carried out on the principle that original paint should not be retouched, but that missing areas should be replaced in those cases where the original appearance could reasonably be deduced.

The exhibition is supplemented by photographs of the panels before and after restoration, and of a selection of comparative material. It is open from 10 a.m. to 6 p.m. on weekdays and from 2.30 to 6 p.m. on Sundays. Admission is free.

BRITISH ASSOCIATION MEETING

The 118th Annual Meeting of the British Association for the Advancement of Science will be held in Sheffield from 29th August to 5th September, 1956, under the presidency of Sir Raymond Priestley, M.C. The meeting's scientific programme will this year be particularly concerned with industry, while present explorations in Antarctica, and the forthcoming International Geophysical year are also among the subjects to be discussed. There will, in addition to the lectures and discussions given in each section of the meeting, be the usual showings of scientific films, social functions, and excursions.

Membership of the British Association is open to all, no scientific qualifications being necessary. The membership fee is two guineas for adults and 10*s*. for students and school-children. Details of this, and of the meeting, can be obtained from the Secretary, British Association, Burlington House, Piccadilly, London, W.1.

OBITUARY

MR. W. H. GALLIENNE

We record with regret the death, at his home in Guernsey on 17th July, of Mr. W. H. Gallienne, British Ambassador to Cuba.

Wilfred Hansford Gallienne, C.B.E., was born in Guernsey in 1897. He served in France during the first years of the 1914–18 war, but after a serious wound was seconded in 1917 to the War Office. In 1919 he entered the Consular Service, being appointed Vice-Consul at Marseilles. He later served in Algiers and Chicago, and after a period in Central America, where in 1930, as Chargé d'Affaires and Consul at Santa Dominco he was special Envoy for the inauguration of the President, was sent to Tallinn, Esthonia, as Chargé d'Affaires and Consul. He remained in that post until 1940, being appointed Minister shortly before he left Tallinn in the same year. In 1942 he was appointed Consul-General in Chicago, and in 1947 became Minister to Guetemala. In 1954 he was promoted Ambassador, and transferred to Cuba. He was appointed C.B.E. in 1931.

Mr. Gallienne was elected a Fellow of the Society in 1949.

SHORT NOTES ON BOOKS

THE EARTH IS MY CANVAS. *By Percy V. Cane, Methuen*, 1956. 42*s*

Gardens which have been designed by the author, who is well known as a garden architect, are here described. Each individual site presents a challenge to the designer, and Mr. Cane gives in each case a full account of the problem, and how it was solved. There are many half-tone plates, and some line illustrations.

THE BRITISH JOURNAL PHOTOGRAPHIC ALMANAC. *H. Greenwood & Co., Ltd.*, 1956. 8*s* 6*d*

Articles on various aspects of photography are combined with general sections on such subjects as chemicals, flash photography, three-colour photography, and a review of photographic apparatus and materials in the current volume of this Almanac, now in its 97th year.

ENJOYING MODERN ART. *By Sarah Newmeyer. New York, Reinhold*, 1955. 40*s*

Beginning with neo-classicism the author, who for 15 years was publicity director of the Museum of Modern Art, New York, traces for the lay reader the development of art in the nineteenth and twentieth centuries. Her theme is the evolution of art

as communication, and many illustrations are provided, mainly of paintings now in American collections.

RENOLD CHAINS. *By Basil H. Tripp. Allan & Unwin,* 1956. 21*s*

In tracing the history of one company from 1879 to 1955, the rise of the precision chain industry is described. To-day the precision chain is an essential method of transmitting driving power in machinery; this little-known piece of engineering development is in this account linked with the technical, business and human problems facing industry as a whole.

SIMPLE PERSPECTIVE. *By Arthur R. Brown. Crosby Lockwood,* 1956. 6*s*

Perspective drawing of a plan gives a greater sense of how the finished produce is intended to look than can be conveyed to the layman by either the various systems of metric projections, or by orthographic projection. In this book the method is described with line diagrams.

MODERN OFFICE BUILDINGS. *By Michael Rosenauer. Batsford,* 1955. 35*s*

The practical aspects of office building are here discussed by the architect of the Time and Life Building in Bond Street, London. Examples of work in nine countries are given with over 100 illustrations, the author having worked in Vienna and London before going to America.

FROM THE JOURNAL OF 1856

VOLUME IV. *8th August,* 1856

HOLIDAY TRAVEL

From a report on Public Health

The following is extracted from the Registrar-General's last Quarterly Report:

'At this season of the year, when many people are travelling on the continent, as well as in England, it may be useful to state that it is now well established, by extensive observation, that England is the healthiest country in Europe. France stands next to England in salubrity. In the continental cities the annual rate of mortality is seldom less than 30 in 1,000; and the rate frequently rises to 40 in 1,000. In London, the rate of mortality is 25 in 1,000.

'On an average of ten years (1841–50) the mortality was at the annual rate per 1,000 of 15 in three English districts, 16 in 14 districts, 17 in 47 districts, 18 in 87 districts. These facts prove that the climate of England is eminently salubrious; and it has not yet been shown that the climate of any part of the continent is equally or more salubrious than this island, crowned with hills of moderate elevation, sloping towards the east and the south; bathed by the showers of the Atlantic, drained naturally by rivers running short courses to the sea, cultivated more extensively than other lands, and producing those unequalled breeds of sheep, cattle, and horses, which flourish only in healthy places.

' . . . and it should be always borne in mind in selecting places of resort that, through the peculiar nature of zymotic diseases, places usually healthy are periodically visited by epidemics, which can only be avoided by consulting recent returns, or by actual inquiries on the spot. The cleansing and the sewerage of all water-places require improvement, as their arrangements were made when sanitary science was at a low ebb'.

ERRATUM

It is regretted that the name of Sir Cyril Hinshelwood, M.A., D.Sc., P.R.S., Dr. Lee's Professor of Chemistry, University of Oxford, was incorrectly given on page 671 of the last issue of the *Journal* as Sir Charles Hinshelwood.

LIBRARY ADDITIONS

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